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Tagging Experiments on the Sand Flounder, *Rhombosolea plebeia* (Richardson), in Canterbury, New Zealand, 1964 to 1966

by
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Fisheries Research Division
New Zealand Ministry of Agriculture and Fisheries

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[National Publicity Studios photo

Frontispiece: The entrance to the Heathcote-Avon Estuary, one of the three tagging areas in the Canterbury study.

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FOREWORD

THE sand flounder, which is widely distributed in shallow water around New Zealand, is of considerable local economic significance. Annual landings fluctuate substantially and during poor years there has been the inevitable assumption of overfishing. Thus it is important to understand not only the biology and behaviour of the species, but also the fishing mortality and the status of the stocks.

Dr Colman had the difficult task of analysing and interpreting the results of earlier tagging work by Dr Mundy and then combining them with his own observations. Nevertheless, he has produced a valuable account of the studies in the Canterbury area which show growth and movement, and he has been able to derive natural and fishing mortalities. Even more importantly, he has shown that though year class strengths will vary, the stocks are not under threat from present fishing pressure.

G. DUNCAN WAUGH,
Director, Fisheries Research Division

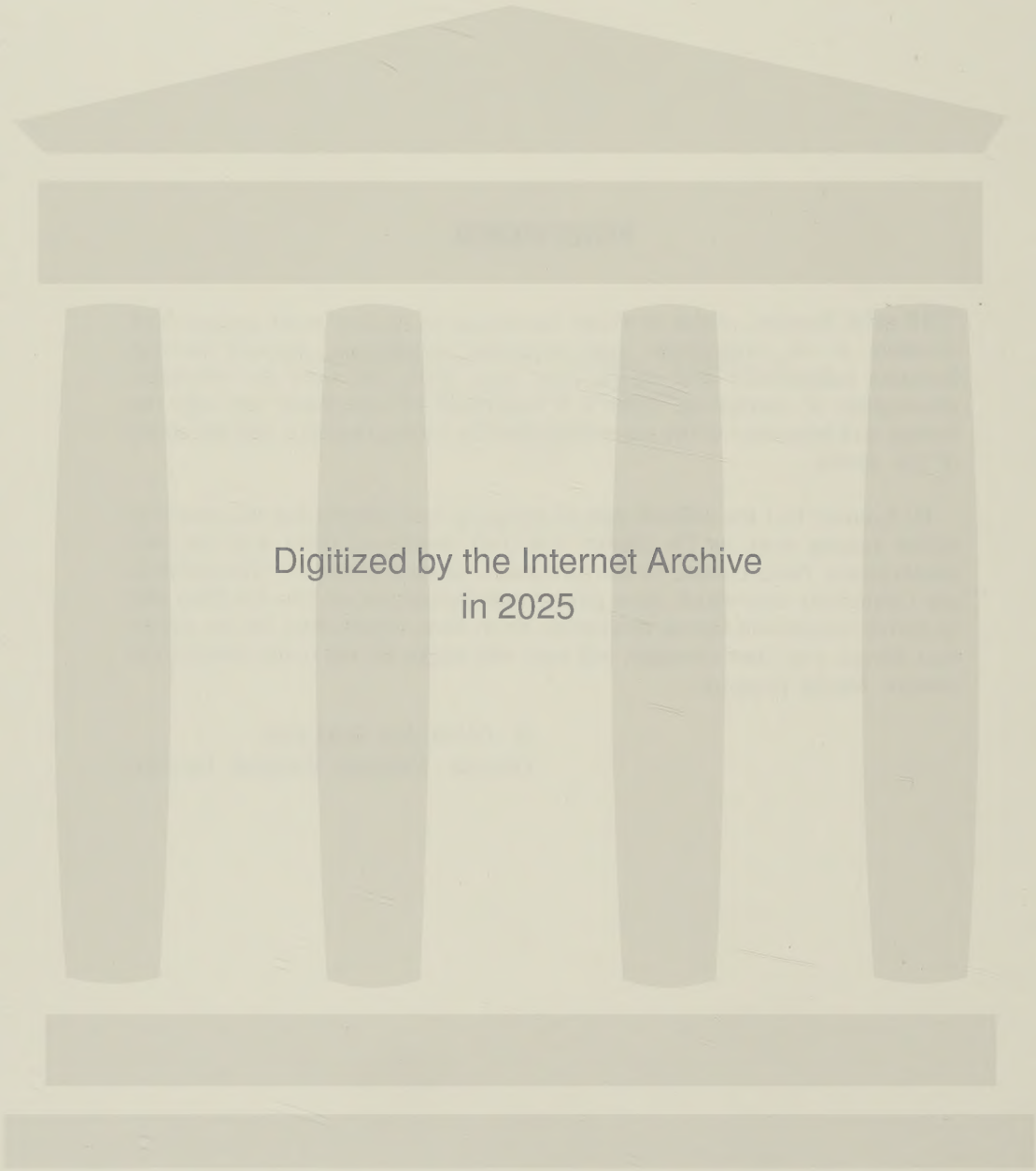

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Fig. 1: Principal fishing grounds for the sand flounder, *Rhombosolea plebeia*, round the coasts of New Zealand.

INTRODUCTION

The sand flounder, *Rhombosolea plebeia* (Richardson), is a typical flatfish of the order Heterosomata, placed by Norman (1934) in the subfamily Rhombosoleinae of the family Pleuronectidae. Thirteen species of flatfish are known from New Zealand waters, of which all but two (*Arnoglossus scapha* (Forster *in* Bloch and Schneider), the New Zealand witch or megrim, and *Lophonectes gallus* Günther, the crested flounder) belong to this subfamily.

Four species, all of the genus *Rhombosolea* Günther, are landed in New Zealand as "flounder." The black flounder, *R. retiaria* Hutton, and the greenback flounder, *R. tapirina* Günther, are taken only in small quantities; the two species of economic importance are the sand flounder and the yellow-belly flounder, *R. leporina* Günther.

The sand flounder is the most abundant of these species and is found in most of the coastal waters of New Zealand down to depths of about 50 m. It is most numerous round the South Island, where the principal flounder fishing grounds are in Tasman Bay and off the east coast (Fig. 1). Sand flounders are also taken off the west coast and in many North Island waters, but in the north of the North Island the yellow-belly flounder is generally of greater economic importance.

Early studies of the biology of the sand flounder were made in Otago waters by Anderton (1907) and Thomson and Anderton (1921), working at the Portobello Marine Biological Station. Little further information was published until Tunbridge's (1966) account of the growth and movements of flatfish, including the sand flounder, in Tasman Bay. Tunbridge (1966) also quoted unpublished information, collected by scientific staff of the New Zealand Marine Department's Fisheries Division (now incorporated in the New Zealand Ministry of Agriculture and Fisheries), which described the movements and growth of sand flounders in Canterbury and Otago waters.

More recently James (1969, 1970) studied mesh selection and escapement of flatfish, including sand flounders, in the Otago trawl fisheries. Robertson and Raj (1971) described the egg and yolk-sac stages of the sand flounder, and Raj (1973) investigated its methods of osmoregulation. Colman (1972, 1973, 1974a, 1974b) published information on the biology of the sand flounder and yellow-belly flounder in the Hauraki Gulf. Webb (1972, 1973a, 1973b) included data on sand flounders and yellow-belly flounders in studies on fish populations in the Heathcote-Avon Estuary, and Mundy (1968) obtained much information on the biology of the sand flounder in Canterbury waters. Some of the data collected by Mundy from 1964 to 1966 while he was employed by the Fisheries Research Division form the basis of this bulletin.

MATERIAL AND METHODS

From 1964 to 1966, 15 051 sand flounders between 15 and 45 cm in length were tagged in the vicinity of Banks Peninsula (Fig. 2). Of these, 5767 fish were tagged in the Heathcote-Avon Estuary, 5894 in Akaroa Harbour, and 3390 in Lyttelton Harbour (Table 1 and Tables 11, 12, and 13 in the Appendix).

TYPES OF TAG USED

Four types of tag were used: single Petersen disc, double Petersen disc, clipped spaghetti, and tied spaghetti. The single Petersen disc consisted of a yellow plastic disc, 13 mm in diameter, threaded on to a stainless steel wire staple which had been pushed through from the blind side 1 to 2 cm below the dorsal fin and about two-thirds of the way back from head to tail. The double Petersen disc was similarly attached, but with a second disc threaded on to the middle of the staple so that a disc was fixed on each side of the body. The spaghetti tag consisted of a length of marked yellow plastic tubing about 30 cm long and 0.15 cm in diameter. This was drawn through the body of the fish below the dorsal fin and either crimped with a copper ring (clipped spaghetti tag) or

TABLE 1: Numbers of sand flounders tagged in each tagging area and the numbers and percentages subsequently recovered in each size group

Length (mm)	Estuary Tagged	Estuary Re-covered	Estuary % rec.	Akaroa Tagged	Akaroa Re-covered	Akaroa % rec.	Lyttelton Tagged	Lyttelton Re-covered	Lyttelton % rec.	Total Tagged	Total Re-covered	Total % rec.
150-170	75	9	12	98	12	12	42	5	12	215	26	12
170-180	1 165	242	21	617	79	13	433	51	12	2 215	372	17
180-190	1 255	244	19	647	88	14	407	58	14	2 309	390	17
190-200	1 202	257	21	664	113	17	355	56	16	2 221	426	19
200-210	958	213	22	645	114	18	317	53	17	1 920	380	20
210-220	608	155	25	640	120	19	322	68	21	1 570	343	22
220-230	312	82	26	620	132	21	276	74	27	1 208	288	24
230-240	57	19	33	483	108	22	237	67	28	777	194	25
240-250	42	18	43	418	87	21	209	57	27	669	162	24
250-260	28	11	39	308	62	20	204	51	25	540	124	23
260-270	27	17	63	163	29	18	145	44	30	335	90	27
270-280	17	9	53	106	30	28	134	45	34	257	84	33
280-290	7	4	57	80	24	30	91	42	46	178	70	39
290-300	10	5	50	61	15	25	88	31	35	159	51	32
>300	4	2	50	344	80	23	130	67	52	478	149	31
Total	5 767	1 287	22	5 894	1 093	19	3 390	769	23	15 051	3 149	21

securely tied. Tied spaghetti tags were used for most of the tagging work, as they were found to be more easily and quickly attached.

FISHING METHODS

In Lyttelton and Akaroa Harbours sand flounders were taken by trawling with a 6.3-cm (2.5-in.) mesh otter trawl. They were held for tagging in a tank supplied with running sea water and were released soon after tagging. In the Heathcote-Avon Estuary fish were taken by beach seine and were held in a galvanised wire-mesh cage before being tagged and released at the water's edge. All of these tagged fish were measured and the lengths recorded to the nearest millimetre.

RECORDING OF DATA

Most returns were from professional and amateur fishermen, though some recaptures were made by Fisheries Research Division personnel. The principal data required from recaptured fish were the length and sex, with the date and location of capture.

The numbers of fish marked with each type of tag in each area, and the numbers of these fish subsequently recovered, are shown in Tables 11, 12, and 13 in the Appendix. The data were subdivided to give the results separately for each 1-cm length group from 15 to 30 cm and for each 5-cm length group from 30 to 45 cm. In practice few fish under 17 cm or over 35 cm long were tagged, and none exceeded 45 cm in length. No fish were sexed before being tagged and released, and so separate returns for males and females could not be obtained.

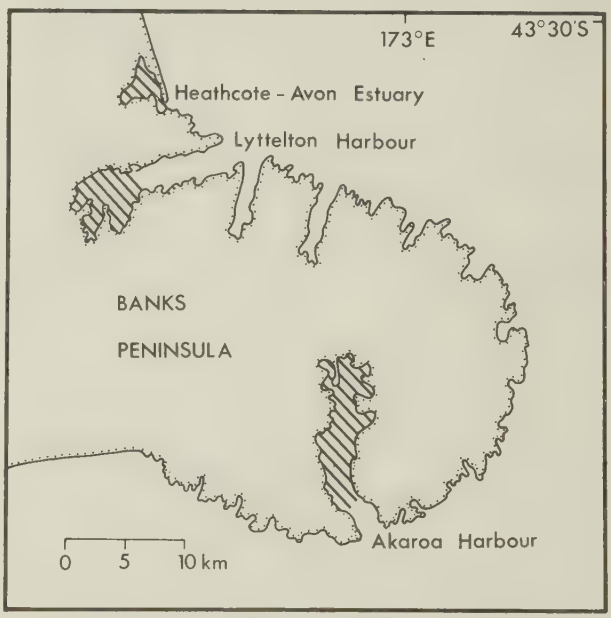


Fig. 2: The locations of the three tagging areas.

COMPARISON OF TAG TYPES AND TAGGING AREAS

It was clear that the proportion of marked fish that were recovered varied between tagging areas and that the length-frequency distributions of tagged fish also differed from area to area (Table 1). The fish were therefore taken by size groups, and comparisons of recovery rate were made between fish tagged in different areas and with different types of tag. Where numbers of fish in length groups were small, groups were combined and a chi-squared test was used to determine significant differences in recovery rate between areas and between fish tagged with different types of tag in each area (Tables 14 and 15 in the Appendix).

COMPARISON OF RECOVERY RATE BETWEEN TAGGING AREAS

Within size groups there were significant differences (at 0.1%) between the returns from the different tagging areas (Table 2). The overall return rate of Akaroa-tagged flounders was also significantly different (at 0.1%) from that of the fish tagged in either of the other areas, but there was no significant difference in overall return rate between fish tagged in the Heathcote-Avon Estuary and in Lyttelton Harbour.

COMPARISON OF RECOVERY RATE WITH DIFFERENT TYPES OF TAG

The recovery rates of fish tagged with the different types of tag were compared within each tagging area (Table 3).

Only tied and clipped spaghetti tags were used in the Heathcote-Avon Estuary, where a significant difference (at the 5% level) was found between the overall return rates with these tags. However, though clipped tags gave consistently higher returns within size groups than tied spaghetti tags, the difference within size groups was not significant at the 5% level.

In Akaroa and Lyttelton Harbours single and double Petersen discs were used, as well as tied and clipped spaghetti tags. In Lyttelton Harbour no significant difference in return rate was detected between any two types of tag.

Among the Akaroa fish significant differences (at the 0.1% level) were found between the return rates with tied and clipped spaghetti tags, both within size groups and over all, with clipped tags giving consistently better returns.

Significant overall differences at the 5% level were also found among Akaroa fish between tied spaghetti tags and double Petersen discs and between clipped spaghetti tags and single Petersen discs. Double Petersen discs and clipped spaghetti tags gave higher returns than tied spaghetti tags and single Petersen discs respectively in nearly all size groups, though except for one size group (25-26 cm, clipped spaghetti/single Petersen disc) the differences were not significant at the 5% level.

TABLE 2: Values and levels of significance of χ^2 obtained by comparing recapture rates between different tagging areas

Tag type	Significance test	Estuary-Akaroa	Estuary-Lyttelton	Akaroa-Lyttelton
Tied spaghetti	$\Sigma\chi^2$*	75.266 (11)†, sig. at 0.1%	28.276 (11), sig. at 1%	41.995 (13), sig. at 0.1%
	Pooled χ^2‡	22.703 (1), sig. at 0.1%	0.587 (1), not sig.	24.529 (1), sig. at 0.1%
	Inter. χ^2	52.563 (10), sig. at 0.1%	27.689 (10), sig. at 1%	17.466 (12), not sig.
Clipped spaghetti	$\Sigma\chi^2$	9.172 (6), not sig.	14.008 (6), sig. at 5%	11.171 (12), not sig.
	Pooled χ^2	0.156 (1), not sig.	0.055 (1), not sig.	0.014 (1), not sig.
	Inter. χ^2	9.016 (5), not sig.	13.953 (5), sig. at 5%	11.157 (11), not sig.
Single Petersen disc	$\Sigma\chi^2$	..§	..	3.176 (2), not sig.
	Pooled χ^2	..	..	0.023 (1), not sig.
	Inter. χ^2	..	..	3.153 (1), not sig.
Double Petersen disc	$\Sigma\chi^2$	..	..	4.798 (3), not sig.
	Pooled χ^2	..	..	1.985 (1), not sig.
	Inter. χ^2	..	..	2.813 (2), not sig.
All tags	$\Sigma\chi^2$	82.723 (12), sig. at 0.1%	41.678 (12), sig. at 0.1%	44.061 (14), sig. at 0.1%
	Pooled χ^2	20.324 (1), sig. at 0.1%	0.129 (1), not sig.	18.392 (1), sig. at 0.1%
	Inter. χ^2	62.399 (11), sig. at 0.1%	41.549 (11), sig. at 0.1%	25.669 (13), sig. at 5%

*$\Sigma\chi^2$ = sum of χ^2 obtained from comparisons within size groups.
† Degrees of freedom are shown in parentheses.
‡ Pooled χ^2 = value of χ^2 obtained from comparisons between all sizes of fish together.
§ No data.

TABLE 3: Values and levels of significance of χ^2 obtained by comparing recapture rates, within tagging areas, of fish tagged with different types of tag

Tags compared	Significance test	Estuary	Akaroa	Lyttelton
Tied spaghetti/ clipped spaghetti	$\Sigma\chi^2$*	12.249 (6)†, not sig.	32.919 (12), sig. at 0.1%	15.698 (13), not sig.
	Pooled χ^2‡	4.975 (1), sig. at 5%	26.155 (1), sig. at 0.1%	0.663 (1), not sig.
	Inter. χ^2	7.274 (5), not sig.	6.764 (11), not sig.	15.035 (12), not sig.
Tied spaghetti/ single Petersen disc	$\Sigma\chi^2$	..§	4.837 (9), not sig.	3.028 (2), not sig.
	Pooled χ^2	..	0.789 (1), not sig.	1.339 (1), not sig.
	Inter. χ^2	..	4.048 (8), not sig.	1.689 (1), not sig.
Tied spaghetti/ double Petersen disc	$\Sigma\chi^2$	..	10.735 (10), not sig.	2.126 (3), not sig.
	Pooled χ^2	.	5.541 (1), sig. at 5%	1.084 (1), not sig.
	Inter. χ^2	.	5.194 (9), not sig.	1.042 (2), not sig.
Clipped spaghetti/ single Petersen disc	$\Sigma\chi^2$	..	15.442 (9), not sig.	3.163 (2), not sig.
	Pooled χ^2	..	6.633 (1), sig. at 5%	2.016 (1), not sig.
	Inter. χ^2	.	8.809 (8), not sig.	1.147 (2), not sig.
Clipped spaghetti/ double Petersen disc	$\Sigma\chi^2$	..	8.680 (10), not sig.	0.451 (3), not sig.
	Pooled χ^2	..	1.836 (1), not sig.	0.423 (1), not sig.
	Inter. χ^2	..	6.844 (9), not sig.	0.028 (2), not sig.
Single/double Petersen discs	$\Sigma\chi^2$	..	8.303 (8), not sig.	2.605 (2), not sig.
	Pooled χ^2	..	1.189 (1), not sig.	2.576 (1), not sig.
	Inter. χ^2	..	7.114 (7), not sig.	0.029 (1), not sig.

*$\Sigma\chi^2$ = sum of χ^2 obtained from comparisons within size groups.
† Degrees of freedom are shown in parentheses.
‡ Pooled χ^2 = value of χ^2 obtained from comparisons between all sizes of fish together.
§ No data.

Returns were plotted against time for each type of tag in each area (Figs. 3, 4, and 5) as percentages of numbers tagged, both cumulatively and as returns within each 3-monthly period after tagging.

For fish tagged in Lyttelton Harbour and the Estuary, only tied and clipped spaghetti tags could be compared, because only a few fish at Lyttelton, and none at the Estuary, were tagged with Petersen discs. In both areas a higher proportion of clipped tags were returned over all, but the patterns of returns differed slightly between the two areas. Among the Estuary fish (Fig. 3) more tied tags than clipped tags were returned in the first 7 or 8 months after tagging, but clipped tags were returned later in greater numbers. At Lyttelton (Fig. 4) the reverse was true.

At Akaroa (Fig. 5) clipped spaghetti tags were returned in consistently higher proportions than tied tags at all times. For the first 6 months both types of Petersen disc were returned at rates comparable to that of tied spaghetti tags. Later they were returned in greater proportions, particularly double Petersen discs, which were the bulk of the tags returned after 2 years.

DISCUSSION

Among the Estuary fish the steeper decline in return rate of tied spaghetti tags compared with that of clipped tags after the first few months implied that the tied ones either were lost at a faster rate or caused higher mortalities than the clipped tags. The results from the Lyttelton fish suggested the opposite, though the differences were not pronounced.

At Akaroa clipped tags were consistently returned at a higher rate than tied tags, which could be interpreted as meaning that a significant proportion of tied tags were lost a short time after tagging. The rate of decline in returns of tied tags at Akaroa also appeared steeper than that of clipped tags, at least for the first year and a half, which suggested that tied tags continued to be lost at a greater rate during this period.

At Akaroa, the only locality where adequate numbers of fish were tagged with Petersen discs, the rate of decline in returns of single and, especially, double Petersen discs was less than for either type of spaghetti tag. This suggested that Petersen discs were retained better by the fish than the spaghetti tags or caused less post-tagging mortality. The initial return rate of Petersen discs was lower, though, which could mean that some discs were lost soon after tagging or, more likely, because of the extra time needed to attach Petersen discs, the tagging mortality was higher when Petersen discs were used.

The rate of return of fish tagged in Akaroa Harbour was clearly lower than that of fish tagged in either of the other areas, both over all and in nearly all of the separate size groups (Table 1). Between the fish tagged in the Heathcote-Avon Estuary and in Lyttelton Harbour there was little difference in the overall rate of return, even though within size groups the rate of return of Estuary-tagged fish was significantly higher.

This apparent discrepancy was caused by the preponderance of small fish in the Estuary, among which the rate of return was low compared with larger fish. The overall return rate in the Estuary was therefore relatively low, even though the return rate within size groups was the highest of all three areas.

The differences in recovery rate between sand flounders tagged at each of the three localities could be attributed mainly to differences in the fishing effort, particularly among the larger fish, which could be expected to be more vulnerable to fishing operations.

The rate of change of fishing mortality with increase in fish size also appeared to vary between stations (see page 17). This could be contributory to the significant values of the heterogeneity chi-squared test obtained in comparing the return rates of fish from the tagging areas (Table 2).

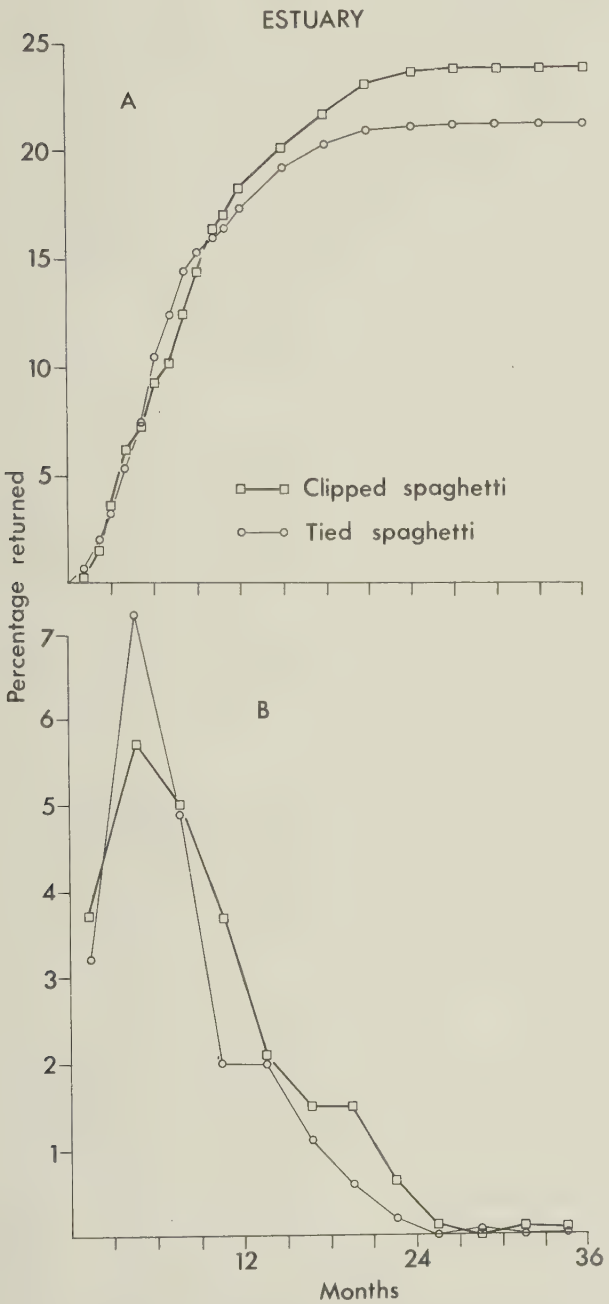


Fig. 3: Returns of different types of tag from fish tagged in the Estuary. A: Cumulative total. B: Returns in each 3-month period.

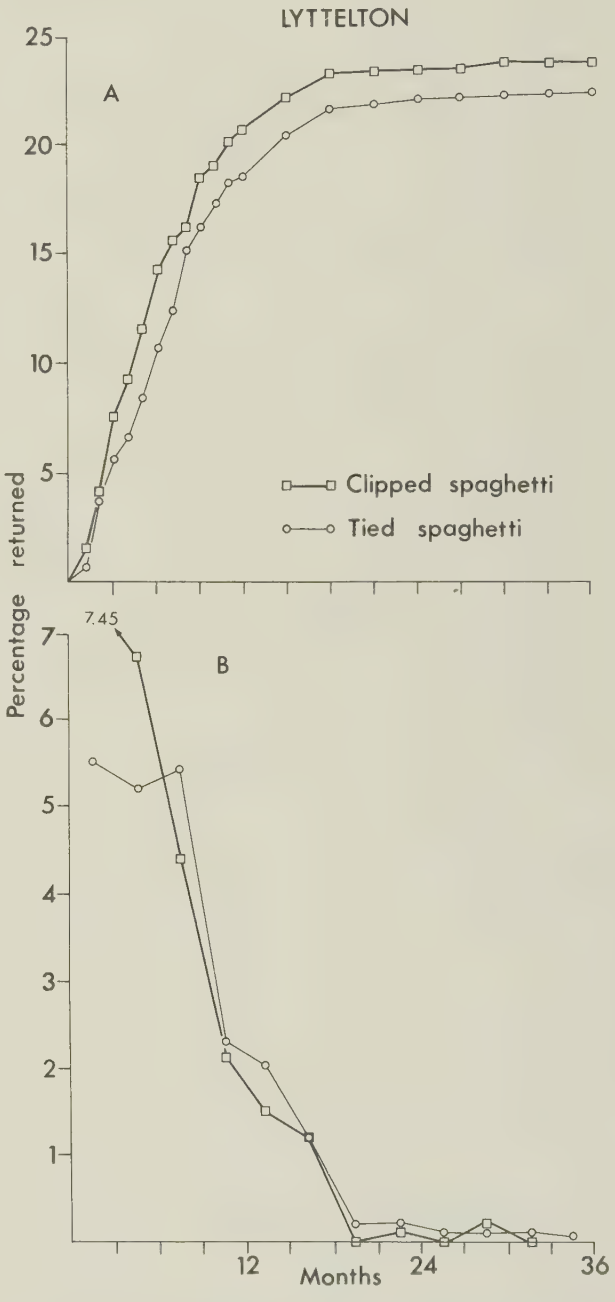
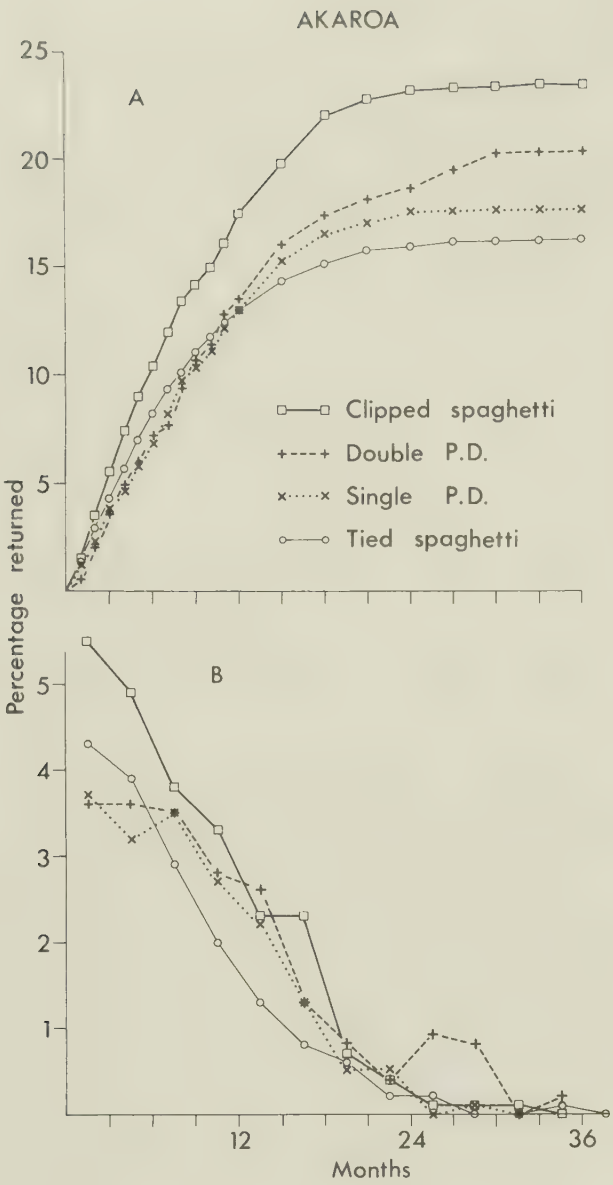


Fig. 4: Returns of different types of tag from fish tagged in Lyttelton Harbour. A: Cumulative total. B: Returns in each 3-month period.



Except for the comparison between tied and clipped spaghetti tags at Akaroa, levels of significance, when present at all, were low despite the numbers of fish generally being large. It was therefore concluded that though the differences in effectiveness between types of tag were small, clipped spaghetti tags gave a higher rate of return than tied tags and were probably also superior to single Petersen discs. Double Petersen discs appeared to be comparable in effectiveness with clipped spaghetti tags, and single Petersen discs with tied spaghetti tags.

Clipped spaghetti tags or double Petersen discs can therefore be expected to give the highest rates of return and the best estimates of mortality rates. Because tied spaghetti tags are attached more quickly and easily than the other types, it may still be preferable to use them if large numbers of fish are being marked and the estimation of their mortality rates is of secondary importance.

Fig. 5: Returns of different types of tag from fish tagged in Akaroa Harbour. A: Cumulative total. B: Returns from each 3-month period.

RECOVERY RATE

The proportion of fish recovered varied with the size of the fish at the time of tagging (Table 1, Fig. 6), returns from fish tagged at a larger size being consistently higher than those from fish that had been tagged when small. In each length group the numbers of fish returned in each year after tagging were recorded (Table 4). Almost all returns (about 98.5%) were made within 2 years of the fish being tagged, and no fish were returned later than 4 years after being marked.

ESTIMATION OF MORTALITY RATES

The logarithms of the numbers of fish recaptured in each year were plotted against time (Fig. 7), the fish being taken in four size groups at the time of tagging (15-19 cm, 19-23 cm, 23-30 cm, and 30-45 cm). These groupings were chosen to give two groups below and two above the legal minimum size of 23 cm. The resulting curves were approximately linear, which indicated constant rates of fishing and natural mortality, but because of the small numbers of points on each line the shapes of the curves could not be determined with precision.

From the recapture data the apparent annual and instantaneous rates of natural, fishing, and total mortality were calculated (Table 5), the method outlined by Seber (1973, pages 271 to 274) being followed. The data were divided so that the four size groups of fish defined above were taken separately. Information was not available on the fishing effort, but it was assumed to be constant from year to year.

In all groups the instantaneous rate of total mortality (Z) was high, generally lying between 1.4 and 2.1. This was equivalent to an annual mortality rate of between 75% and 88%. Among the small fish the greater part of the total mortality appeared to be due to natural mortality (M), which had a value of about 1.2, equivalent to an annual natural mortality rate of about 70%. The natural mortality rate remained fairly constant throughout all sizes of sand flounders and also appeared to be similar among fish from all three tagging areas. Variations in M were generally of only one or two standard deviations (Table 5) and could be explained by sampling variation inherent in the recapture process.

In contrast to this, the fishing mortality (F) varied considerably between fish tagged in the different areas. Variations between areas and between size groups were considerably greater than the standard deviations (Table 5) and could not reasonably be explained solely by sampling variation. In fish from the Heathcote-Avon Estuary and Lyttelton Harbour the fishing mortality rose rapidly as the size of the fish increased, and among the large fish the fishing mortality was comparable with the natural mortality. Among the fish tagged in Akaroa Harbour the fishing mortality also increased with the size of the fish at tagging, but the rate of increase of fishing mortality

TABLE 4: Numbers of sand flounders tagged in each area and the numbers subsequently recovered in each year after tagging

Length group (cm)	Estuary					Akaroa					Lyttelton				
		Number recovered each year after tagging					Number recovered each year after tagging					Number recovered each year after tagging			
	Number tagged	First year	Second year	Third year	Fourth year	Number tagged	First year	Second year	Third year	Fourth year	Number tagged	First year	Second year	Third year	Fourth year
15-16	2	0	1	0	0	13	1	1	0	0	2	0	0	0	0
16-17	73	7	1	0	0	85	7	3	0	0	40	4	1	0	0
17-18	1 165	174	65	2	1	617	61	14	3	1	433	39	12	0	0
18-19	1 255	185	59	0	0	647	60	27	1	0	407	45	12	1	0
19-20	1 202	199	56	2	0	664	89	22	2	0	355	48	5	2	1
20-21	958	162	50	1	0	645	79	31	4	0	317	38	13	1	1
21-22	608	128	26	1	0	640	87	31	2	0	322	49	18	1	0
22-23	312	71	10	1	0	620	100	30	1	1	276	61	10	2	1
23-24	57	16	3	0	0	483	70	32	5	1	237	57	10	0	0
24-25	42	17	1	0	0	418	56	25	5	1	209	54	3	0	0
25-26	28	11	0	0	0	308	51	11	0	0	204	40	11	0	0
26-27	27	17	0	0	0	163	20	8	1	0	145	41	3	0	0
27-28	17	8	1	0	0	106	21	9	0	0	134	42	3	0	0
28-29	7	4	0	0	0	80	21	3	0	0	91	35	7	0	0
29-30	10	5	0	0	0	61	13	2	0	0	88	30	1	0	0
30-35	3	2	0	0	0	251	47	10	0	0	124	58	6	0	0
35-40	0	0	0	0	0	85	17	2	1	0	4	2	0	0	0
40-45	1	0	0	0	0	8	3	0	0	0	2	1	0	0	0
Total	5 767	1 006	273	7	1	5 894	803	261	25	4	3 390	644	115	7	3

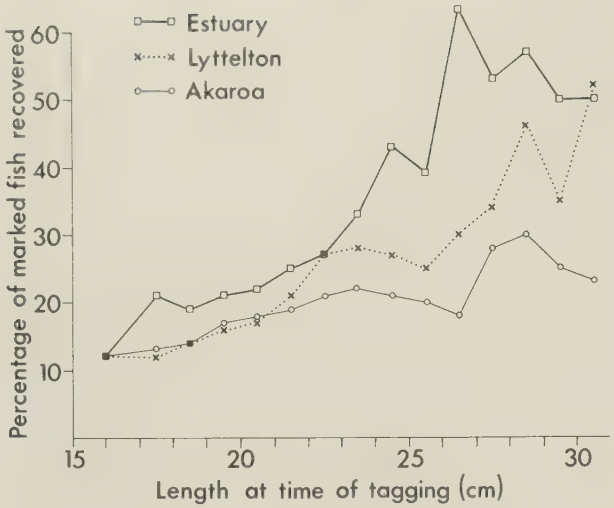


Fig. 6: Percentages of marked fish recovered in each length group.

with size was much less than in the other areas. Even among the largest fish tagged at Akaroa the instantaneous fishing mortality rate was only about 30% of the instantaneous natural mortality rate.

DISCUSSION

The rates of return calculated from the available data are all likely to be too low owing to sources of error inherent in the tagging methods (see Ricker 1958). Two important sources of error, neither of which can be determined in this instance, are (1) deaths of fish, or loss of tags, shortly after tagging and attributable to the tagging operation, and (2) incomplete reporting of tags recovered. Errors of this kind will result in an underestimate being made of the mortality due to fishing.

Further error may result from a change in fishing effort from year to year. Most tagged fish left the in-shore tagging areas during the first year after tagging and did not return, as shown by the small numbers recovered in the tagging areas during subsequent years (Tables 6, 7, and 8). In all years except the first, therefore, they would be subject to the rate of fishing on the off-shore grounds, which can be assumed to be relatively constant, but during part of the first year after tagging the fish would be subject to the rate of fishing on the tagging grounds. This is likely to be different from that on the off-shore grounds and, furthermore, different sizes of fish may be affected to varying degrees.

There was, for instance, an indication that returns for the first year after tagging were low compared with what would have been expected from the trend of the curves during subsequent years. This could be due either to a lower rate of fishing on the in-shore tagging grounds, where fish were taken mainly during the first year after tagging, or to the fish becoming more vulnerable to fishing as they grew older and larger.

It was apparent (Table 5) that the fishing mortality was higher among fish tagged at larger sizes. Therefore, among a batch of similarly sized fish at the time of tagging the fishing mortality rate can be expected to rise each year as the fish grow larger.

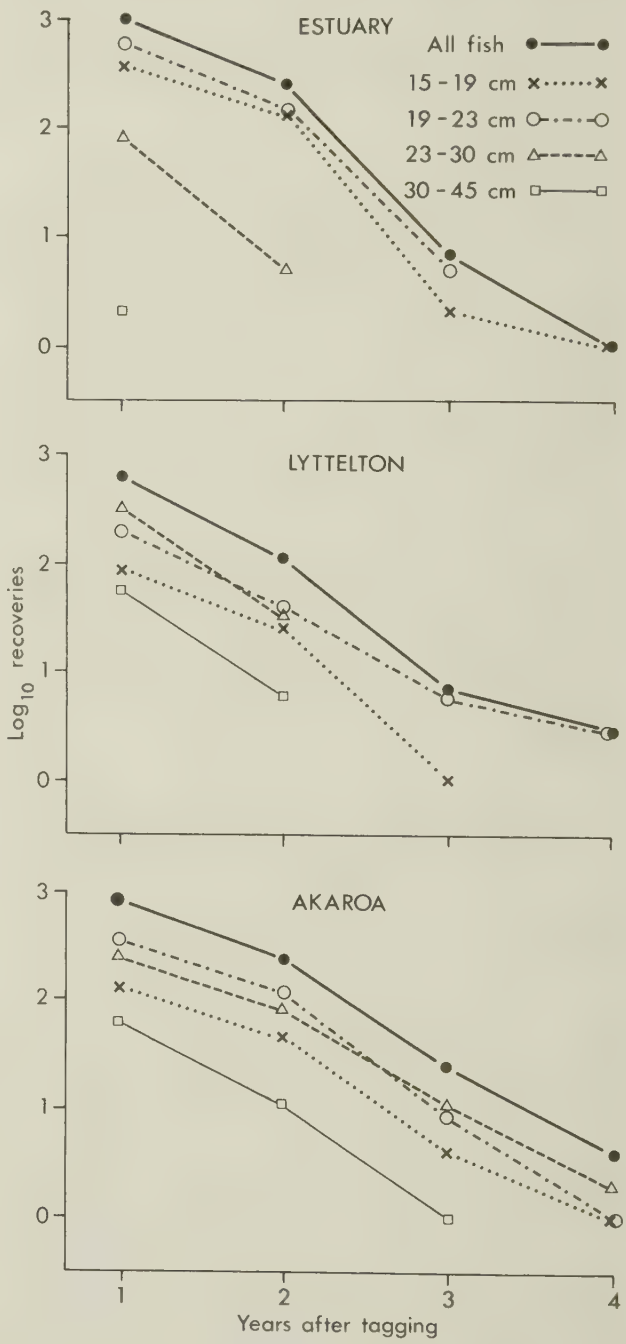


Fig. 7: Logarithms of the numbers of sand flounders marked in each area that were recovered in each year after release.

Factors such as emigration from the fishing grounds, steady loss of tags, and higher mortality rates among tagged fish will all cause the natural mortality rate to be overestimated. In this investigation emigration from the fishing grounds is likely to be of little importance, since only small numbers of

TABLE 5: Values and standard deviations of instantaneous mortality rates due to fishing (F), natural causes (M), and all causes combined (Z), obtained from sand flounders tagged in each of three areas, and comparable annual mortality rates

Area	Length (cm)	Number tagged	Number recovered	Instantaneous mortality rates			Standard deviations of			Annual mortality rates		
				F	M	Z	F	M	Z	Fishing $(1 - e^{-F})$	Natural $(1 - e^{-M})$	Total $(1 - e^{-Z})$
Estuary	15-19	2 495	495	0.277	1.118	1.395	0.017	0.027	0.063	0.24	0.67	0.75
	19-23	3 080	707	0.365	1.225	1.590	0.018	0.029	0.060	0.31	0.71	0.80
	23-30	188	83	0.916	1.159	2.075	0.126	0.141	0.231	0.60	0.69	0.87
	30-45	4	2	..*	..	..	..	..	..	..	..	..
	Total	5 767	1 287	0.342	1.192	1.534	0.013	0.020	0.043	0.29	0.70	0.78
Akaroa	15-19	1 362	179	0.193	1.275	1.468	0.020	0.042	0.110	0.18	0.72	0.77
	19-23	2 569	479	0.276	1.205	1.481	0.017	0.030	0.068	0.24	0.70	0.77
	23-30	1 619	355	0.314	1.119	1.433	0.022	0.034	0.076	0.27	0.67	0.76
	30-45	344	80	0.386	1.273	1.659	0.057	0.091	0.188	0.32	0.72	0.81
	Total	5 894	1 093	0.274	1.204	1.478	0.011	0.019	0.045	0.24	0.70	0.77
Lyttelton	15-19	882	114	0.196	1.322	1.518	0.025	0.055	0.143	0.18	0.73	0.78
	19-23	1 270	251	0.305	1.240	1.545	0.026	0.044	0.098	0.26	0.71	0.79
	23-30	1 108	337	0.584	1.337	1.921	0.041	0.059	0.105	0.44	0.74	0.85
	30-45	130	67	1.120	1.053	2.173	0.167	0.169	0.270	0.67	0.65	0.89
	Total	3 390	769	0.395	1.345	1.740	0.019	0.031	0.063	0.33	0.74	0.82

* Numbers of fish were too small to permit calculation.

TABLE 6: Numbers of sand flounders recovered in different areas* at different times after being tagged in the Heathcote-Avon Estuary (area 8)

Year after tagging	Time of year	Area of recovery									
		1	2	3	4	5	6	7	8	9	10
First	January	149	23	2	2	3	0	0	7	0	0
	February	27	10	1	0	1	0	0	11	3	0
	March	19	12	0	2	0	0	0	8	0	0
	April	7	1	0	1	0	0	0	23	0	0
	May	3	3	0	0	0	0	0	38	0	2
	June	2	2	0	1	0	1	0	24	0	2
	July	3	3	0	1	1	5	0	36	0	1
	August	2	22	0	1	2	6	0	19	1	0
	September	16	33	0	2	4	5	0	16	0	1
	October	36	52	2	2	1	4	0	23	0	1
	November	89	58	3	3	0	5	0	14	0	0
	December	58	27	2	3	0	1	0	9	1	1
	Annual total	411	246	10	18	12	27	0	228	5	8
Second	Dec-Feb	27	1	0	3	1	0	0	1	0	0
	Jan-Mar	9	3	0	1	1	0	0	1	1	0
	Feb-Apr	15	0	0	2	1	1	0	1	0	0
	Mar-May	2	0	0	3	0	1	0	3	0	0
	Apr-Jun	3	0	0	1	0	0	0	1	0	0
	May-Jul	0	0	0	0	0	1	0	0	0	0
	Jun-Aug	2	15	0	3	4	11	0	9	0	0
	Jul-Sep	2	2	0	1	2	4	0	0	0	0
	Aug-Oct	7	13	0	1	2	8	0	0	0	0
	Sep-Nov	11	11	0	1	1	5	0	1	0	0
	Oct-Dec	24	7	0	3	1	5	0	1	0	0
	Nov-Jan	20	2	0	1	0	0	0	0	0	0
	Annual total	122	54	0	20	13	36	0	18	1	0
Third		3	1	0	1	0	2	0	0	0	0
Fourth		0	0	0	0	0	0	0	1	0	0
	Grand total	536	301	10	39	25	65	0	247	6	8

* See Fig. 11.

TABLE 7: Numbers of sand flounders recovered in different areas* at different times after being tagged in Lyttelton Harbour (area 10)

Year after tagging	Time of year	Area of recovery 1	2	3	4	5	6	7	8	9	10
First	January	67	8	0	1	3	0	0	0	0	3
	February	27	0	1	1	1	1	0	0	0	6
	March	5	3	0	0	0	0	0	1	0	18
	April	3	1	0	0	0	0	0	0	1	36
	May	4	0	0	0	0	0	0	0	1	93
	June	3	1	0	0	0	0	0	3	0	45
	July	0	7	0	1	1	1	0	0	0	23
	August	0	17	0	1	3	3	0	0	0	7
	September	9	16	0	0	2	0	0	1	0	5
	October	24	16	1	0	0	3	0	0	0	8
	November	72	13	1	0	0	4	1	0	0	7
	December	31	4	0	0	2	0	0	0	1	5
	Annual total	245	86	3	4	12	12	1	5	3	256
Second	Dec-Feb	2	0	0	1	0	0	0	0	0	1
	Jan-Mar	5	0	0	1	1	1	0	0	0	0
	Feb-Apr	5	0	0	1	0	0	0	0	0	0
	Mar-May	0	1	0	0	0	0	0	0	0	5
	Apr-Jun	4	0	0	0	0	4	0	0	0	10
	May-Jul	2	1	0	0	0	0	0	0	0	3
	Jun-Aug	1	0	0	0	0	3	0	0	0	1
	Jul-Sep	0	7	0	0	1	6	0	0	0	1
	Aug-Oct	1	4	0	0	0	2	0	0	0	0
	Sep-Nov	1	0	0	2	0	1	0	0	0	0
	Oct-Dec	10	8	0	1	0	0	0	1	0	0
	Nov-Jan	9	0	0	1	0	0	0	0	0	0
	Annual total	40	21	0	7	2	17	0	1	0	21
Third		2	0	0	0	0	5	0	0	0	0
Fourth		1	0	0	0	0	0	0	0	0	2
	Grand total	288	107	3	11	14	34	1	6	3	279

* See Fig. 11.

TABLE 8: Numbers of sand flounders recovered in different areas* at different times after being tagged in Akaroa Harbour (area 9)

Year after tagging	Time of year	Area of recovery 1	2	3	4	5	6	7	8	9	10
First	January	2	13	2	2	0	1	0	0	63	0
	February	3	13	3	2	1	1	0	0	86	1
	March	1	6	0	3	0	5	0	0	64	0
	April	0	3	0	0	0	2	0	0	76	0
	May	0	5	0	0	0	1	0	0	45	0
	June	1	1	0	0	0	6	0	1	8	0
	July	0	6	2	0	0	11	3	0	26	0
	August	0	23	0	2	2	8	2	0	30	0
	September	0	40	0	1	5	6	1	0	31	0
	October	1	20	0	4	4	2	0	0	29	0
	November	3	20	1	9	0	1	0	0	29	0
	December	1	8	0	0	1	3	1	0	31	0
	Annual total	12	158	8	23	13	47	7	1	518	1
Second	Dec-Feb	1	4	0	0	1	1	0	0	2	0
	Jan-Mar	1	17	0	6	1	2	1	0	6	0
	Feb-Apr	2	3	0	2	0	4	0	1	4	0
	Mar-May	1	0	0	1	0	1	0	0	3	0
	Apr-Jun	0	0	0	1	0	2	0	0	0	0
	May-Jul	0	4	0	1	1	0	0	0	5	0
	Jun-Aug	0	2	0	0	0	3	0	0	0	0
	Jul-Sep	0	12	0	0	1	7	0	0	2	1
	Aug-Oct	0	19	2	4	2	8	0	0	0	0
	Sep-Nov	0	9	0	0	0	2	0	0	3	0
	Oct-Dec	2	28	0	6	3	11	1	0	1	0
	Nov-Jan	2	14	2	2	0	8	0	0	2	0
	Annual total	9	112	4	23	9	49	2	1	28	1
Third		1	5	2	4	5	6	0	0	2	0
Fourth		0	0	0	1	0	0	0	0	2	1
	Grand total	22	275	14	51	27	102	9	2	550	3

* See Fig. 11.

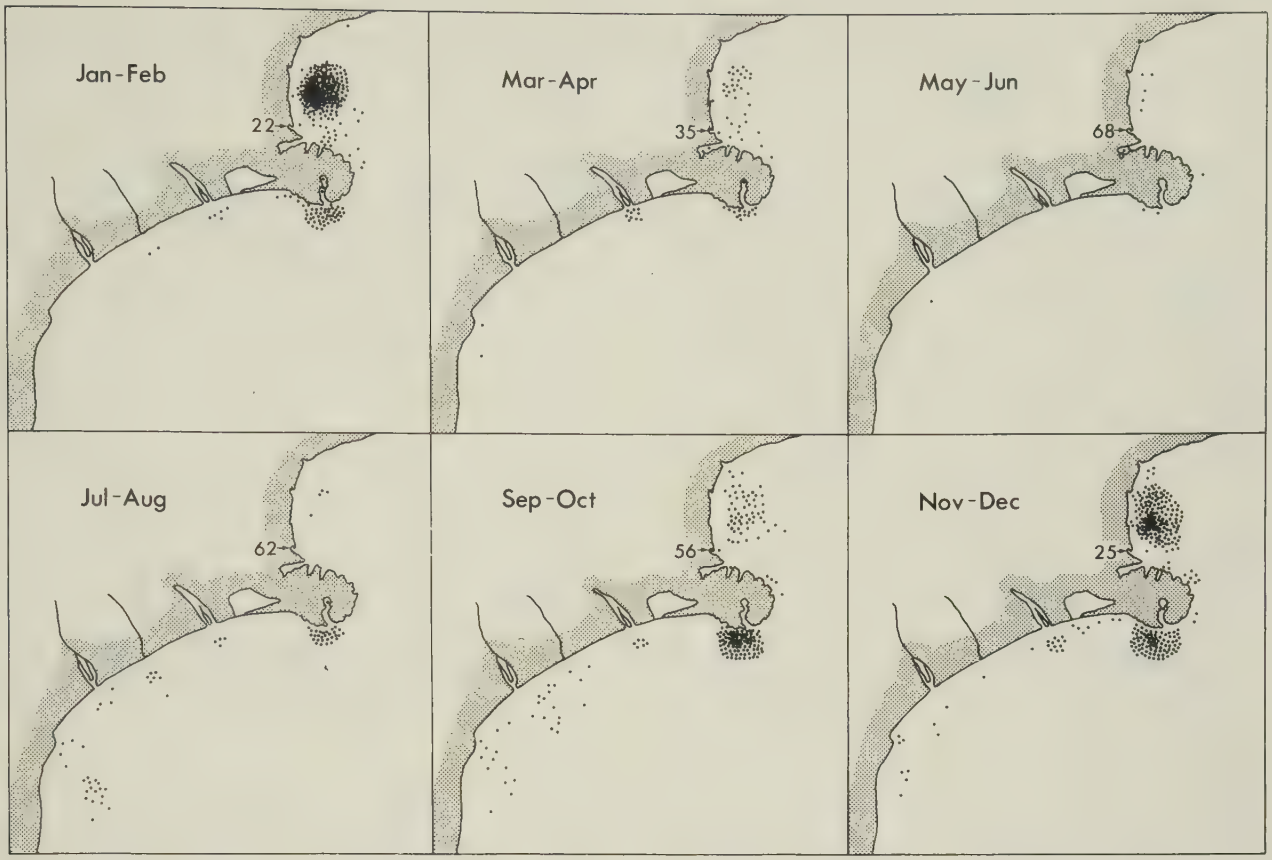


Fig. 8: Positions of recapture of sand flounders tagged in the Heathcote-Avon Estuary and subsequently recovered outside the tagging area at different times of the year.

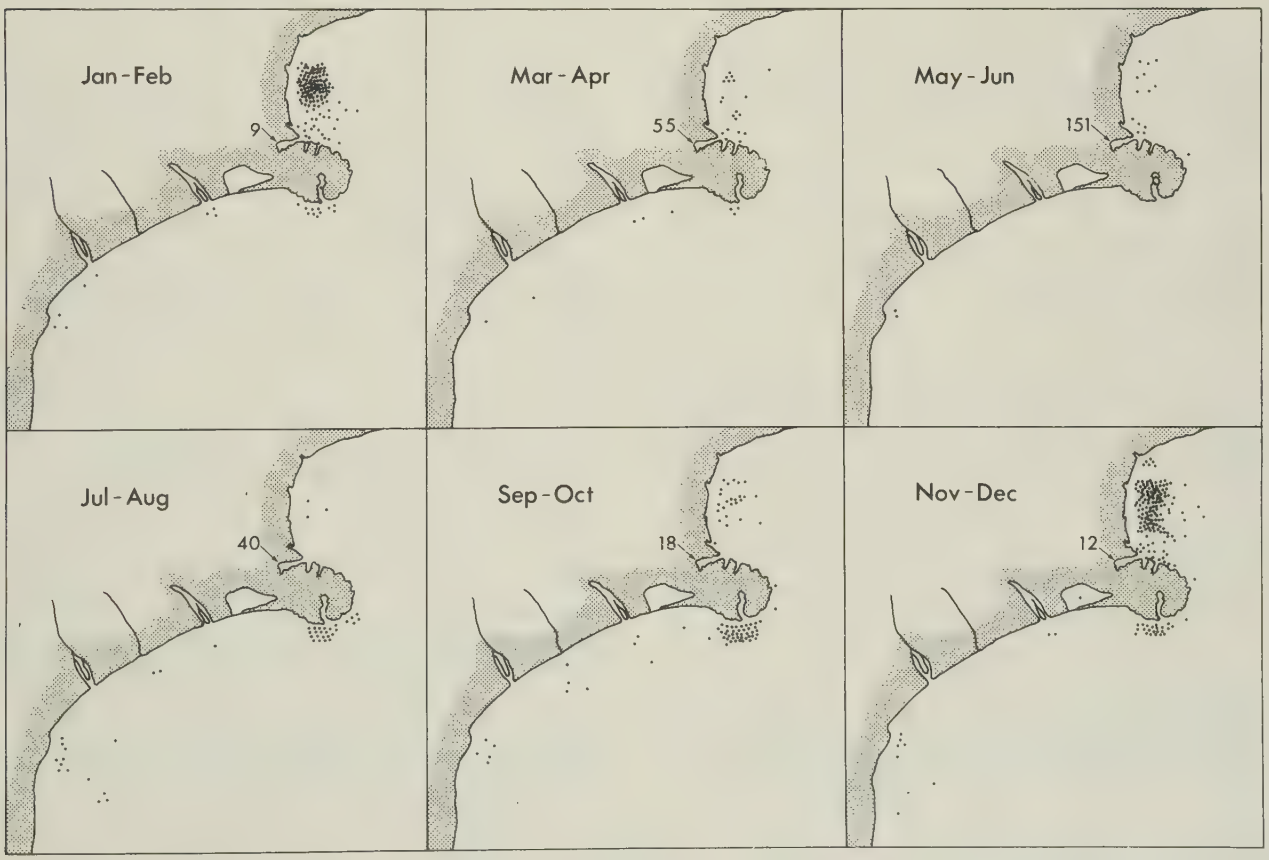


Fig. 9: Positions of recapture of sand flounders tagged in Lyttelton Harbour and subsequently recovered outside the tagging area at different times of the year.

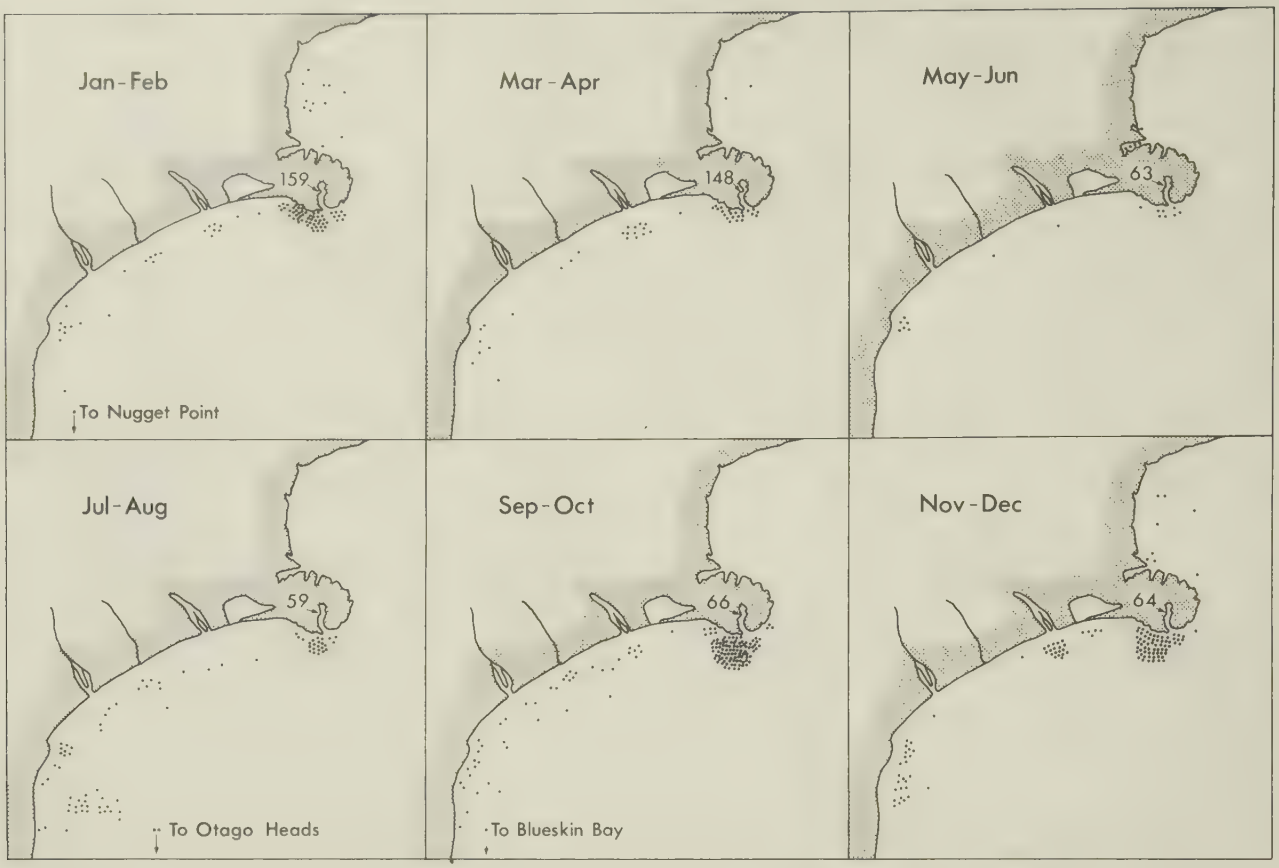


Fig. 10: Positions of recapture of sand flounders tagged in Akaroa Harbour and subsequently recovered outside the tagging area at different times of the year.

recovered fish had travelled far from the tagging sites, but the other two factors are almost certainly involved.

Because of these sources of error the mortality rates shown in Table 5 can be regarded as only approximate. Fishing mortality is probably underestimated and natural mortality is almost certainly overestimated.

The natural mortality rate was found to be constant among fish of all sizes tagged in each of the three tagging areas. In contrast fishing mortality varied both with the size of the fish and with the area in which the fish were tagged. The rise in fishing mortality with increasing size is to be expected because of increasing vulnerability to fishing gear, though the fishing mortality rate can be expected to stabilise once the fish are fully recruited to the exploited stock.

Among sand flounders tagged below the legal minimum size of 23 cm the fishing mortality rates were of the same order in all three tagging areas, though rather higher in the Heathcote-Avon Estuary than in Lyttelton or Akaroa Harbours.

Among the larger fish, however, the fishing mortality among fish tagged in Akaroa was markedly lower than that of fish tagged in the other two areas. The reason for this probably lies in the different distribution pattern of fish tagged in the Estuary (Table 6, Fig. 8) and in Lyttelton Harbour (Table 7, Fig. 9) compared with that of the Akaroa-tagged fish (Table 8, Fig. 10). Among the Estuary and Lyttelton fish most off-shore returns were made from Pegasus Bay and Akaroa Heads. In contrast very few fish tagged in Akaroa Harbour were subsequently recovered in Pegasus Bay, most returns being made from Akaroa Heads and the Canterbury Bight. The lower fishing mortality among Akaroa-tagged fish can therefore be explained by a lower intensity of fishing in the Canterbury Bight compared with Pegasus Bay.

Differences in fishing intensity within the tagging areas do not explain the low fishing mortality among Akaroa-tagged sand flounders, because the proportion of fish recovered within the tagging area of Akaroa Harbour was the highest of all three areas. This suggests that the fishing mortality within Akaroa Harbour is at least as high as that within the other tagging areas.

MOVEMENTS

To follow the movements of sand flounders the study area was divided into 10 regions—the three tagging sites and seven off-shore areas (Fig. 11). The numbers of fish recovered in each of these regions in each month were tabulated, separate tables being compiled for fish tagged in each area. As male and female sand flounder recoveries had essentially the same distribution patterns, data from males and females were combined; data from fish whose sex was not determined were also included.

MOVEMENTS OF FISH TAGGED IN THE HEATHCOTE-AVON ESTUARY

The number of fish recovered from known localities and on known dates was 1237 (Table 6)*. Sometimes the information about a recapture was sufficient to determine the locality only within broad limits (for example, Pegasus Bay), but generally positions of recapture could be determined fairly accurately (Fig. 8).

During the first year after tagging most fish were returned from areas 1 (Pegasus Bay) and 2 (off Banks Peninsula), as well as the tagging site in the Estuary (area 8). Small numbers had moved southwards into the Canterbury Bight (areas 3, 4, 5, and 6), but none were taken to the north of Pegasus Bay. Few fish were recaptured inside Akaroa Harbour or in Lyttelton Harbour.

During the second year after tagging, only small numbers were recaptured within the Estuary. Considerable numbers of Estuary-tagged fish were still taken in Pegasus Bay and in the Banks Peninsula area, particularly near Akaroa Heads. A higher proportion of the total recaptures for the year came from the Canterbury Bight than during the first year after tagging, especially from area 6 in the vicinity of Timaru.

MOVEMENTS OF FISH TAGGED IN LYTTELTON HARBOUR

Fish recaptured at known positions and on known dates totalled 747 (Table 7, Fig. 9). The pattern of returns was essentially similar to that of the fish tagged in the Heathcote-Avon Estuary. Most of the fish recovered during the first year after tagging were taken in Pegasus Bay and round Banks Peninsula and in the tagging area of Lyttelton Harbour. Only a few had moved south into the Canterbury Bight.

The returns from the second year after tagging also resembled those of the Estuary sand flounders, with most fish being taken in Pegasus Bay and round Banks Peninsula and relatively more in the Canterbury Bight compared with the first post-tagging year. The Lyttelton fish moved rather less than those from the Estuary, a higher proportion of the returns of Lyttelton-tagged fish coming from the tagging site and the adjacent waters of Pegasus Bay.

Only 18 fish tagged in the Estuary or in Lyttelton Harbour were recovered later than 2 years after tagging. Three were recaptured within their tagging area and 6 others in Pegasus Bay. Another fish was

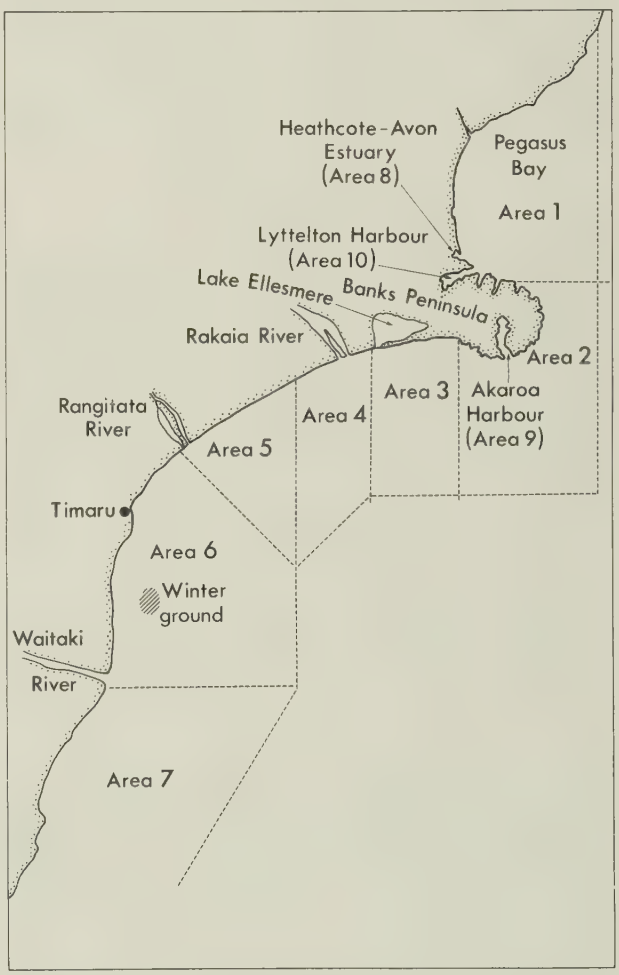


Fig. 11: Limits of the areas off the Canterbury coast within which recaptures were recorded.

*Recaptures plotted in Figs. 8, 9, and 10 are only those whose positions could be determined reasonably precisely. Some second recaptures have also been included in these figures. The numbers do not necessarily agree, therefore, with those in Tables 6, 7, and 8.

recaptured round Banks Peninsula, but the other 8 were all taken in the Canterbury Bight, 7 of them near Timaru. Thus, in each successive year after tagging, an increasing proportion of the sand flounders tagged in the Heathcote-Avon Estuary and in Lyttelton Harbour were recovered from the Canterbury Bight.

MOVEMENTS OF FISH TAGGED IN AKAROA HARBOUR

Fish recovered from known localities and on known dates numbered 1055 (Table 8, Fig. 10). A higher proportion of the returns were made from the tagging area, about two-thirds of all recaptures during the first post-tagging year coming from Akaroa Harbour. Very few fish were recaptured in Pegasus Bay, though large numbers of sand flounders tagged in the other two areas had been recaptured there. Most returns of Akaroa-tagged fish, excluding those recovered within Akaroa Harbour, were made near Akaroa Heads. More were recaptured in the Canterbury Bight than were recovered from flounders tagged in the other two areas, and as with fish from Lyttelton and the Estuary, the proportion of recaptures made in the Canterbury Bight increased with the time that the fish had been at liberty.

SEASONAL MOVEMENTS

For fish tagged in Lyttelton Harbour and in the Heathcote-Avon Estuary, recaptures in the in-shore tagging areas were more frequent during autumn and winter, especially in Lyttelton Harbour, where over 75% of recaptures within the harbour were made in the four months of April to July. Returns from Pegasus Bay were highest during summer, particularly November, December, and January. In area 2, round Banks Peninsula, the largest numbers of sand flounders were taken from August to January, mostly off, and to the west of, Akaroa Heads, in 30 to 45 m of water. Returns from areas 3, 4, and 5 in the Canterbury Bight were sparse and no firm conclusion could be drawn concerning seasonal variation in these areas, but returns from area 6, near Timaru, were markedly higher during winter and spring (mainly July to November).

Thus, during summer fish tagged in the Heathcote-Avon Estuary and in Lyttelton Harbour were recaptured mainly in Pegasus Bay. During winter and spring they were recaptured mainly on the tagging site (during the first year after tagging), round Banks Peninsula (mostly near Akaroa Heads), or in the vicinity of Timaru.

For fish tagged in Akaroa Harbour recaptures off Akaroa Heads were mainly from August to November, but they continued a little longer in the second post-tagging year. Returns from area 6, near Timaru, were mainly in winter and spring from June to September in the first year after tagging and July to December in the second year. These recapture patterns were similar to those for fish from the Heathcote-Avon Estuary and Lyttelton Harbour.

Within the tagging area, however, the pattern of returns differed from those in the other areas, with the highest returns being made from January to May, that is, late summer and autumn. This contrasted with the peak returns during autumn and winter in the other tagging areas.

DISCUSSION

The results showed that most sand flounders left the in-shore tagging areas within a year of being tagged. Increased returns from the off-shore areas, particularly Pegasus Bay and the waters off Akaroa Heads, from August to November indicated that this was the period during which most of the sand flounders moved out. Mundy (1968), who took the nominal "birthday" of the sand flounder as 1 September, concluded that this occurred when the fish were 2 years old. This conclusion is substantiated by my own unpublished data. At this age females average about 23 cm in length, males rather less. Few fish remained on, or later returned to, the tagging grounds.

The off-shore distributions of sand flounders tagged in Lyttelton Harbour and in the Heathcote-Avon Estuary were mainly the same, and these fish could clearly be included in the same population. Akaroa-tagged sand flounders had a different off-shore distribution, mainly being recovered in the Canterbury Bight rather than in Pegasus Bay, where many of the Lyttelton and Estuary fish were caught. The question therefore arose, also considered by Mundy (1968), whether there were two separate populations.

Mundy (1968) suggested that one population spawned in Pegasus Bay, the progeny of this stock colonising the waters of Lyttelton Harbour and the Heathcote-Avon Estuary and other neighbouring nursery grounds, and that another population spawned on the "winter ground," 15 to 20 km south-east from Timaru, supplying larvae to Akaroa Harbour and neighbouring waters. Sand flounders spawn in winter and spring (Tunbridge 1966, Colman 1973, Mundy 1968, Raj 1973) and can be expected to concentrate on their spawning grounds at this time of the year. In area 6 (Fig. 11), which included the "winter ground," larger numbers of sand flounders were recaptured during July to November and this supported Mundy's (1968) hypothesis that this area was a spawning ground for sand flounders.

Sand flounders were recaptured in numbers in Pegasus Bay only between October and February. Although unpublished data I have show that some spawning takes place in Pegasus Bay, on the basis of seasonal distribution of sand flounders it appeared more likely that heavy spawning would occur in area 2, round Banks Peninsula. Fish marked in all three tagging areas were found in area 2 in substantial numbers from August to November, mainly in the waters between 30 m and 45 m in depth off Akaroa Heads.

Thus the sand flounder probably spawns in two localities in Canterbury waters—near Akaroa Heads and in the vicinity of Timaru—but whether the fish spawning in these areas form separate populations is open to question and is being investigated. The nursery grounds round Banks Peninsula clearly supply fish to both of these grounds, and adults from all three tagging areas are found together during the spawning season. It is difficult to see how there can be a degree of isolation sufficient to maintain the separate identities of two spawning populations.

The general southward movement of sand flounders off the east coast of the South Island, also noted by Tunbridge (1966), presumably has the effect of maintaining the flounder populations over the same stretches of coast, since the planktonic eggs and larvae must be carried northwards by the Southland Current (see Heath 1972). Thus fish moving south to spawn in the Canterbury Bight would provide eggs and larvae that would eventually metamorphose near Banks Peninsula and colonise the bays of the area. Fish spawning near Akaroa Heads would provide eggs and larvae settling in Pegasus Bay, though there would probably be considerable overlap in the areas settled by larvae originating from each spawning ground.

GROWTH

The data on growth were analysed for each sex separately. Information was sought on the seasonal variation in growth rate, on the relationship between growth and the size of the fish when tagged, and on the growth rate of sand flounders tagged in each of the three tagging areas.

SEASONAL VARIATION IN GROWTH RATE

Fish were grouped so that all fish tagged in each 3-month period were taken together. For fish tagged in each 3-month period the mean increase in length was calculated for all fish recovered in each 30-day period after tagging. Fish recovered after 360 days at liberty were grouped in 90-day periods. Graphs were then drawn to show the mean increase in length with time (Fig. 12), data taken from small numbers (3 or less) of fish being omitted.

The growth patterns of males and females were essentially similar, though the females generally grew slightly faster and reached larger sizes than the males. In fish of both sexes the growth rate was initially faster in those fish tagged during July to December than in those tagged during January to June. The lowest initial growth rate was among the fish tagged in April to June and the fastest among fish tagged in October to December. Owing to small numbers of recaptures and to a general slowing of growth by the end of the first year after tagging, seasonal variations in growth rate could not be followed among fish which had been tagged for longer than a few months. Nevertheless, it was clear that growth was most rapid during summer and slowest during winter.

VARIATION IN GROWTH WITH TAGGING AREA

The mean increase in length with time was plotted separately for fish tagged in each tagging area (Fig. 13). Males and females were kept separate, but all sizes of fish were included.

Among the male sand flounders there was little apparent difference in growth rate between fish from the different tagging areas, though initially the growth of the Estuary fish seemed to be slightly faster than that of the fish tagged in the other two areas.

Among the females, however, the rate of growth of fish tagged in the Heathcote-Avon Estuary was consistently higher than in the other areas. The growth rates of Akaroa and Lyttelton fish were remarkably similar to each other, at least for the first

year after tagging. Thereafter the Lyttelton fish had larger length increments than those from Akaroa.

The sand flounders tagged in the Heathcote-Avon Estuary were, on average, smaller than those tagged in Lyttelton and Akaroa Harbours. It was thought that this might be the cause of the apparently higher growth rate of the Estuary fish, since it was shown (Fig. 14) that small fish grew more rapidly after tagging than large fish.

The post-tagging growth of female sand flounders from 20 to 25 cm in length was plotted for each area (Fig. 15). This size group was well represented in all areas; within it little variation in growth rate was found between areas, and this agreed with the results for male sand flounders. It was therefore concluded that there was little difference in the rate of growth of sand flounders from these areas.

VARIATION IN GROWTH WITH SIZE AT TAGGING

Both male and female sand flounders were separated into three size groups according to their lengths at the time that they were tagged—fish under 20 cm, fish from 20 to 25 cm, fish over 25 cm in overall length. The mean increase in length with time was plotted for fish in each of these length groups separately (Fig. 14). Both for males and females the

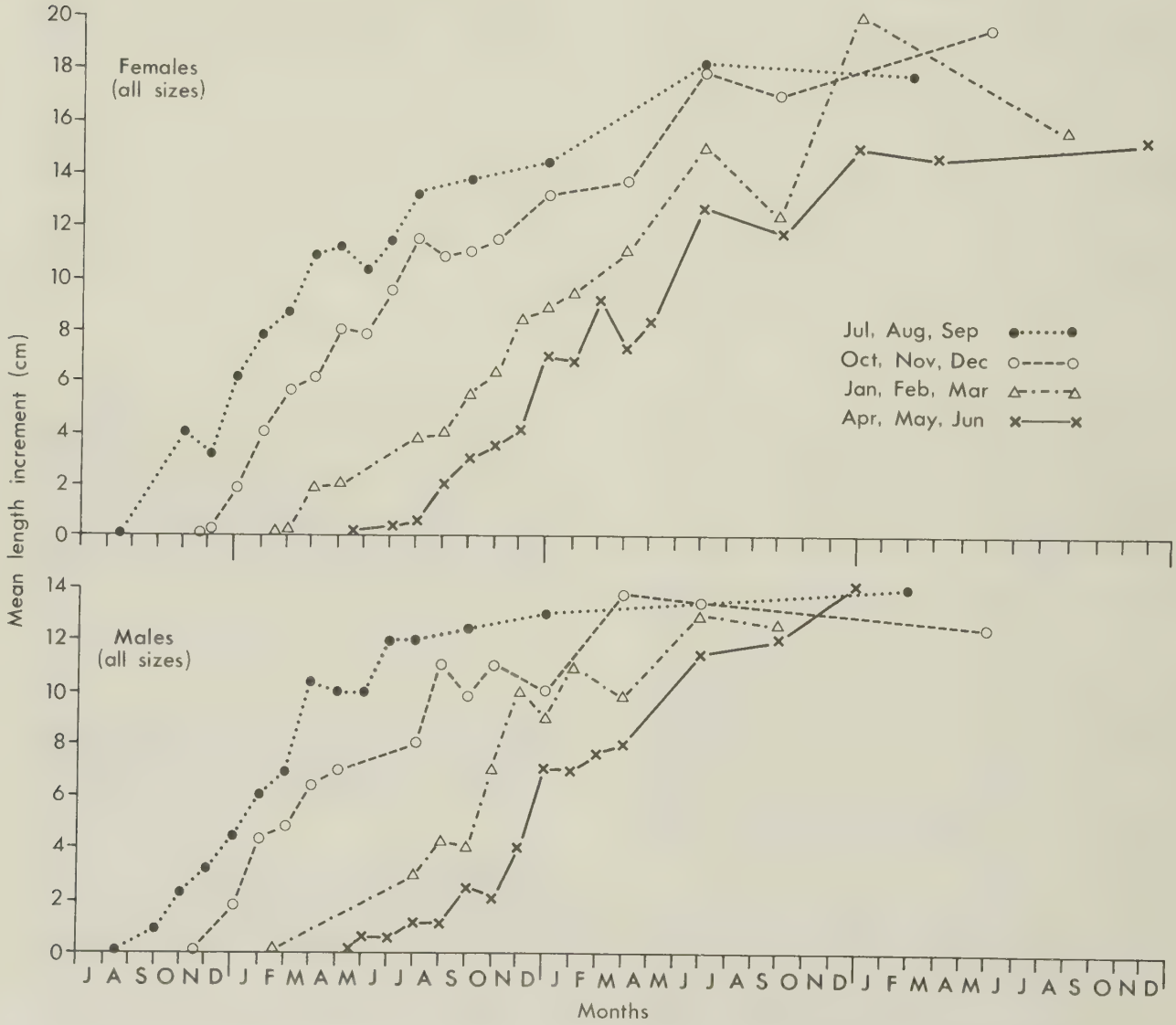

Females
(all sizes)
Males
(all sizes)
Jul, Aug, Sep
Oct, Nov, Dec
Jan, Feb, Mar
Apr, May, Jun
Mean length increment (cm)
Months
J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

Fig. 12: Mean increase in length among sand flounders recaptured at intervals after tagging. Data from fish tagged in each quarter-year have been combined and mean increments calculated for fish recaptured in each 30-day period for the first year after tagging and in each 90-day period during the second year.

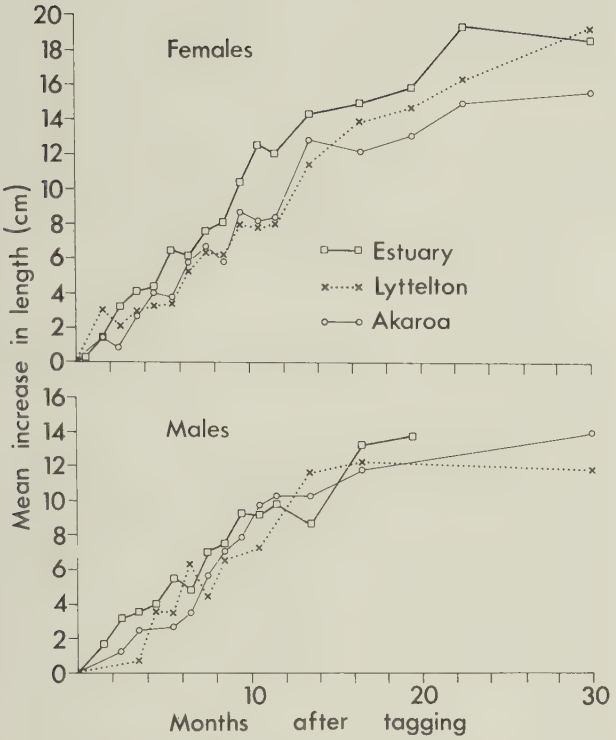


Fig. 13: Mean increase in length, with time, of sand flounders tagged in each tagging area.

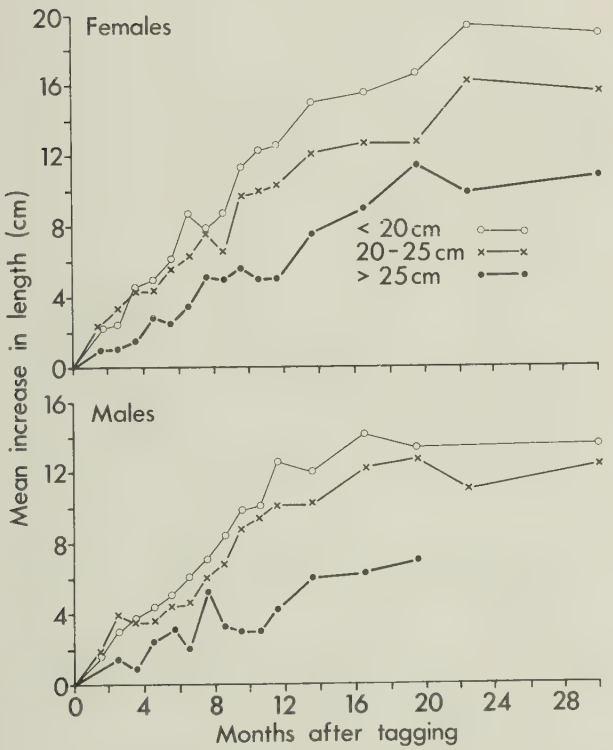


Fig. 14: Mean increase in length, with time, of three size groups of sand flounders. Data from fish marked in all areas at all times have been combined.

growth rate after tagging, and the final increase in length, was less among fish tagged at a large size than among those tagged when small.

Growth can often be described by a Ford-Walford equation (Ford 1933, Walford 1946) and illustrated by a Walford line, which is the regression line of l_{t+1} plotted against l_t. Because no data were available for the ages of the fish tagged, Walford lines for male and female sand flounders were drawn by use of the method of Manzer and Taylor (1947). In this method the length at recapture is plotted against the length at tagging for fish which have been at liberty for 1 year. In practice data from sand flounders which had been at liberty for between 330 and 400 days (that is, 365 ± 35 days) were used. The length at time of recovery (l_{t+1}) was plotted against the length at time of tagging (l_t) for males and females separately. The line fitted was the major axis of the correlation ellipse (Fig. 16), since the regressions of l_{t+1} on l_t and l_t on l_{t+1} are not appropriate (R. L. Allen pers. comm., Ricker 1973). From the plotted curves l_∞ was estimated at 47.7 cm for female sand flounders and 37.4 cm for males (Table 9).

Mundy (1968) derived a von Bertalanffy growth curve for female sand flounders, based on lengths of fish aged by otolith reading, which fitted the equation $l_t = 59.9\ (1 - 0.791^{t+0.083})$. The parameters of this equation are $L_\infty = 59.9$ cm, $t_0 = 0.083$ years, and $K = 0.235$. The figure of 47.7 cm for females is considerably lower than that of 59.9 cm obtained by Mundy (1968), possibly because of a reduced growth rate after tagging, at least among some fish. One of the largest females tagged grew hardly at all (0.4 cm) in the year that it was at liberty, and another large female had a small (1.4 cm) length increment. If the data from these fish are eliminated, the estimate of l_∞ becomes 52.1 cm, a value closer to that obtained by Mundy (1968), but with such a large variation in individual growths it is impossible to reach any precise

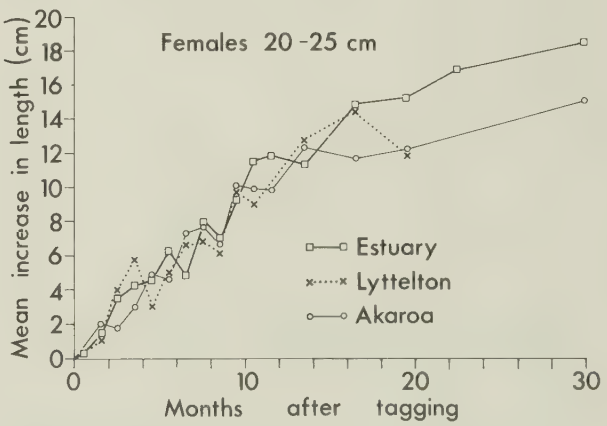


Fig. 15: Mean increase in length, with time, of female sand flounders between 20 and 25 cm tagged in each area.

TABLE 9: Ford-Walford equations for male and female sand flounders*

Sex	Number of fish	Ford-Walford equation	k $(=e^{-K})$	K	l_∞ (cm)
Male	45	$l_{t+1} = 20.7 + 0.458\ l_t$	0.458	0.781	37.4
Female	121	$l_{t+1} = 19.6 + 0.589\ l_t$	0.589	0.530	47.7
Female (Mundy 1968)		$l_{t+1} = 12.5 + 0.791\ l_t$	0.791	0.235	59.9

* Data are taken from fish which had been at liberty for about 1 year. Mundy's (1968) estimates for fish aged by otolith reading are also included.

growth equations with this method. Mundy's (1968) growth equation therefore remains the best available model for the growth of female sand flounders.

DISCUSSION

Tagging experiments have been used in other parts of New Zealand to follow the growth of sand flounders (Tunbridge 1966), but the results have not been entirely satisfactory, mainly because returns were sent in for only a limited period, less than 1 year after tagging, and the numbers of fish returned were small. The figures given for annual increments by Tunbridge (1966) were extrapolated from the mean monthly increment and generally were based on only small numbers of fish.

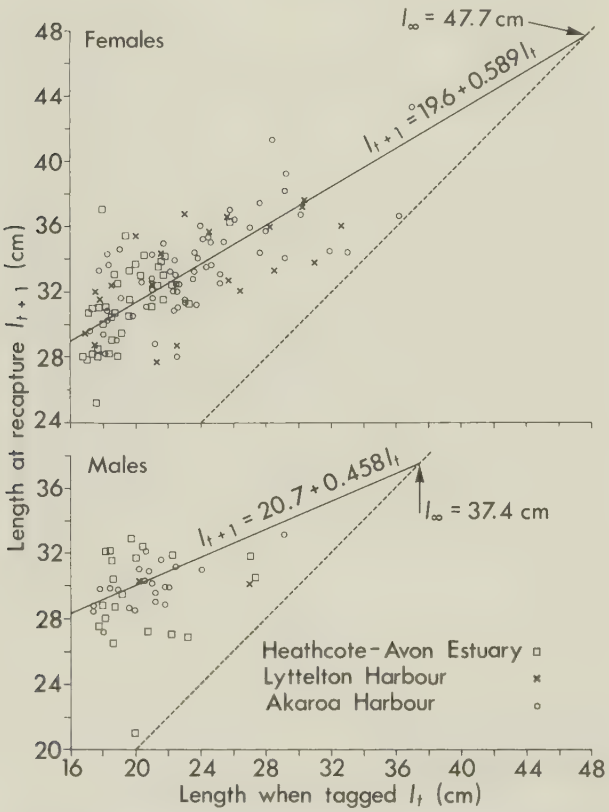


Fig. 16: Length at recapture plotted against length at time of tagging for sand flounders which had been at liberty for between 330 and 400 days.

Nevertheless, the figures quoted by Tunbridge (1966) for sand flounders from 21 to 24 cm in length showed reasonable agreement, with indicated annual increments of 8.2 cm (Canterbury), 8.3 cm (Tasman Bay), 9.5-10.0 cm (Lake Ellesmere), and 10.0-12.5 cm (Otago). Colman's (1974b) results for Hauraki Gulf sand flounders were also comparable with these figures, with female sand flounders growing from about 23 cm at 2 years old to over 30 cm at 3 years. Mundy's (1968) results for female sand flounders in Canterbury waters, based on ages determined by otolith reading, were also similar to these, with calculated mean lengths of 23.1 cm and 30.8 cm at 2 and 3 years old respectively.

The results presented in this bulletin indicate a rather higher rate of growth than that quoted by Tunbridge (1966) for Canterbury sand flounders. Fish between 20 and 25 cm when tagged grew 10-11 cm, on average, during the year after being tagged. Sand flounders tagged at smaller sizes had even larger annual length increments, though large fish grew more slowly.

The fact that no sand flounders larger than 45 cm were caught may be a reflection of the high mortality rate suffered by the species. If it is assumed from the results of Mundy (1968) and Colman (1974b) that female sand flounders of 20-25 cm are about 2 years old, there are few survivors at 4 years of age and virtually none remain alive after 6 years old. At 6 years old the mean length of females, according to Mundy's growth equation, would be 45.5 cm. This agrees well with the fact that 45 cm appears to be close to the upper limit of size for sand flounders caught in the Canterbury fisheries.

The growth pattern that emerged was generally that of a fast-growing fish with a relatively short life span and a high mortality rate.

STATUS OF THE CANTERBURY SAND FLOUNDER FISHERY

The equilibrium yield of a fishery can be estimated by use of any of a number of mathematical models. To set up any of these models information is needed on the growth and mortality rates of the fish in that fishery. Generally it is also necessary to assume that these remain constant with changes in population density and related parameters. This assumption has been made of the sand flounder in the following discussion.

Two methods of calculating equilibrium yields were used, those of Ricker (1945) and Beverton and Holt (1957). Ricker's method has the advantage that rates of growth and mortality need not be taken as constant throughout the life of the fish, though it is assumed that these rates are constant within each interval that is considered. In the following account the flounder population was considered in age intervals of 3 months, from recruitment at 2 years old up to the age of 6 years.

Beverton and Holt's method is less flexible than Ricker's in that parameters of the yield equation must be assumed to be constant throughout the exploited phase of the fish's life. It also depends on the von Bertalanffy growth equation adequately describing the growth of the fish.

The best information available on the growth of the sand flounder in Canterbury waters was obtained by Mundy (1968). He examined the otoliths of 785 previously measured fish, and from the resulting data on age and length he derived a von Bertalanffy growth equation for female sand flounders which fitted the data fairly well. Tag returns, and my own unpublished data, showed that most of the sand flounders taken in the Canterbury fishery were females; so Mundy's growth equation is taken to be representative of the commercially exploited sand flounders in Canterbury waters. In this study of the Canterbury flounder fisheries it was assumed that growth rates and natural mortality rates would not alter with changes in fishing intensity.

The data on natural and fishing mortality rates obtained from the tagging experiments described in this bulletin were used for setting up the yield models. The natural mortality rate appeared to be constant throughout the study area and for different sizes of fish and was assumed to be so. The instantaneous rate of natural mortality (M) appeared to be about 1.2, but, because this was probably an overestimate due to errors inherent in tagging experiments, other lower values of M were also considered. The effect on the yield of varying F (instantaneous rate of fishing mortality) was studied for each of these values.

The tagging results showed that F increased with the size of the fish. For fish from the Estuary and from Lyttelton Harbour F increased from about 0.4 at 23 cm to 1.0, or slightly higher, among fish of 30 cm and over. Among Akaroa fish the increase in F was much less pronounced, from about 0.3 at 23 cm to about 0.4 among large fish.

Ricker's (1945) method was used to calculate yields for a number of values of F and M (Table 10). The age at recruitment was taken to be 2.0 years, at which the mean length is 23.1 cm according to Mundy's (1968) growth equation, which was used to calculate mean lengths at each age, because the raw data on length at age were not available. Weight was assumed to be proportional to the cube of the length, since Mundy (1968) had found no significant departure from this relationship.

Yields were calculated with Ricker's method in two ways. Firstly, yields were calculated with F rising linearly from a value of 0.4 at 2 years old to 1.0 at 3 years old and remaining constant at 1.0 thereafter. This regime, in which the changing value of F was designated a, is close to that indicated for Lyttelton Harbour and Estuary fish. Yields were then calculated for higher and lower values of a. Secondly, yields were calculated with F held constant. The present value of

TABLE 10: Yield* in kg per 1000 kg of recruits at age 2 under different regimes of M and F†

	M			
F	0.6	0.8	1.0	1.2
$0.6a$	1 067	810	642	520
$0.8a$	1 136	898	725	600
a	1 181	954	787	665
$1.2a$	1 202	991	832	712
$1.4a$	1 211	1 016	863	747
$1.6a$	1 216	1 035	891	778
$2.0a$	1 219	1 052	941	823
0.4	913	711	567	466
0.5	1 007	791	653	533
0.6	1 066	851	699	590
0.7	1 110	900	748	633
0.8	1 136	932	788	678
0.9	1 152	960	816	697
1.0	1 168	985	846	740
1.2	1 180	1 017	888	787
1.4	1 184	1 036	918	822
1.6	1 184	1 049	939	853
1.8	1 180	1 057	959	878
2.0	1 174	1 066	976	900

* Yields have been calculated with Ricker's (1945) method with time intervals of 3 months.

† When $F = a$, F increases linearly from an annual rate of 0.4 at 2 years old to 1.0 at 3 years old, remaining at 1.0 thereafter.

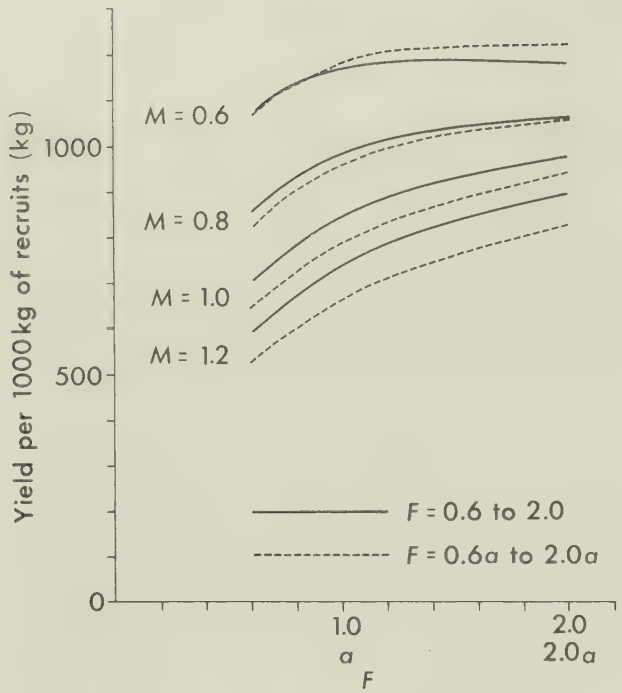


Fig. 17: Yield per 1000 kg of recruits plotted against instantaneous fishing mortality coefficient (F) for varying values of the instantaneous natural mortality coefficient (M), calculated by Ricker's (1945) method. When $F=a$, F increases from 0.4 to 1.0 during the first year of exploitation, remaining at 1.0 thereafter.

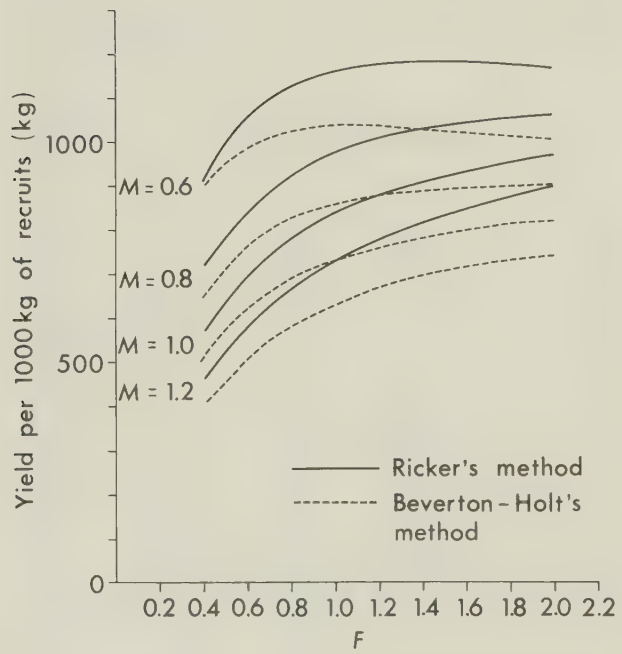


Fig. 18: Yield per 1000 kg of recruits plotted against F for varying values of the instantaneous natural mortality coefficient (M), calculated by Ricker's (1945) and Beverton and Holt's (1957) methods.

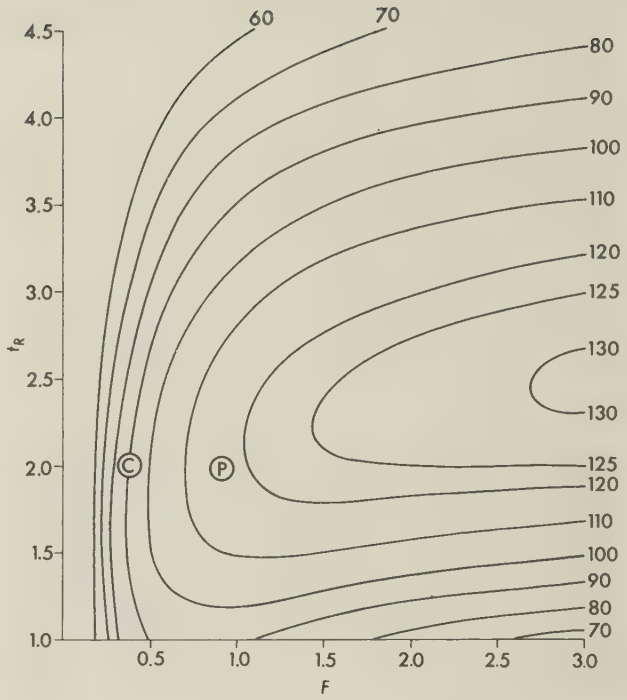


Fig. 19: Yield isopleth diagram for Canterbury sand flounders. Lines join points of equal equilibrium yield (in grams) per recruit. C and P indicate present values of t_R and F in the Canterbury Bight and Pegasus Bay respectively.

F for Akaroa fish, though not perfectly constant, is about 0.4 or slightly less.

Over the range of values of F and M likely to be met in the Canterbury flounder fishery the shape of the yield curves differed only slightly, whether F was considered to be constant or to increase during the first year of exploitation as when $F = a$ (Fig. 17). Therefore the use of a constant value of F to approximate some value of a should not result in major error. Thus methods in which changes in F cannot be accommodated can perhaps be used. Yields were therefore calculated wth Beverton and Holt's (1957) method as a comparison with the yields obtained by Ricker's method, and yield curves obtained by both methods were plotted (Fig. 18).

For values of M between 0.8 and 1.2 the yield was found to increase with higher values of F throughout the range examined. This held true for Ricker's method, whether F was considered to remain constant or to increase during the first year of life, and also for Beverton and Holt's method. For the lower value of $M = 0.6$, maximum yields were obtained at $F = 1.5$ (Ricker's method with F constant) and at $F = 1.1$ (Beverton and Holt's method), though with F increasing during the first year the yield continued to rise slowly up to the value of $F = 2.0$.

The effects of changes in fishing mortality and in size at recruitment can best be examined by means of a yield isopleth diagram (Fig. 19). Beverton and Holt's method was used to construct this diagram, with a value of $M = 0.8$. It is clear from the diagram that changing the size at recruitment from the present value of 23 cm, at 2 years of age, would have little effect on the yield unless the change were large, and that increasing fishing mortality should result in an increase in yield. For larger values of M the increase in yield with increasing F would be more pronounced. However, because the increase in yield would be quite small, especially for fish from Lyttelton and the Estuary, the catch per unit effort would fall steeply.

The present state of the Canterbury flounder fishery therefore appears to be satisfactory, with no danger of the equilibrium yield being adversely affected by fishing pressure, provided recruitment remains at its present level. Because the sand flounder has a high mortality rate, individual fish remain in the fishery for only a short time and the fishery depends almost entirely on fish in their first and second years of exploitation. The yield in any one year therefore depends on the success or otherwise of year classes recruited to the fishery in that year or the preceding year and is therefore likely to fluctuate considerably.

Under the present fishing regime most fish will have a chance to spawn at least once, as they spawn for the first time at 2 years old (Colman 1973 and unpublished data), when they first become vulnerable to fishing.

The effect of fishing operations on spawning success is therefore unlikely to be appreciable. The fecundity of the sand flounder is high (Colman 1973), which further decreases the chances of fishing reducing the numbers of eggs and larvae surviving through to metamorphosis and finally to recruitment.

On the other hand, any long-term reduction in recruitment is bound to have an adverse effect on the overall yields. Variation in spawning success is probably only of minor importance in determining brood strength, compared with factors acting on the planktonic larval stages and on the juvenile fish during the period spent on the nursery grounds. Little is known of the biology of juvenile sand flounders and factors influencing their survival, and until more is known, any action which might adversely affect flounder nursery grounds should be carefully appraised.

SUMMARY

Tagging experiments on the sand flounder, *Rhombosolea plebeia* (Richardson), in the coastal waters of Canterbury between 1964 and 1966 are described. Rates of return are compared among fish of different sizes, tagged in different areas with different types of tag. Movements of sand flounders are traced and growth rates estimated.

The rate of return increased with the size of fish at the time of tagging. Fishing, natural, and total mortality rates were calculated, and the errors inherent in the estimates are discussed. Mortality rates were high; the natural mortality coefficient, M, was constant among all size groups of fish from all tagging areas and was about 0.8 to 1.2. The fishing mortality coefficient, F, increased with the size of fish at the time of tagging and varied with the area of tagging, being lower among fish tagged in Akaroa Harbour, where $F \approx 0.4$. Among fish from the Heathcote-Avon Estuary and Lyttelton Harbour F varied from about 0.4 to 1.0, depending on the size at the time of tagging.

Rates of return varied among fish tagged in different areas and with different types of tag. Clipped spaghetti tags and double Petersen discs generally gave slightly better rates of return than tied spaghetti tags and single Petersen discs.

Most sand flounders left the in-shore tagging areas the first year after tagging. Most recaptures were in the waters adjacent to the tagging areas, with the proportion of recaptures made to the south of Banks Peninsula increasing in each year after tagging.

Growth rates were similar in fish from all tagging areas. Males grew more slowly than females and did not reach as large a size. Owing to the high mortality rate, no sand flounders approached the theoretical maximum size.

The status of the Canterbury sand flounder fishery is discussed. The effect on the equilibrium yield of varying fishing effort and size at recruitment was investigated.

ACKNOWLEDGMENTS

The data on which this paper is based were collected by A. R. Mundy, scientist on the staff of the Fisheries Research Division, who was then studying for the degree of Ph.D. at the University of Canterbury. Little of his work was published, but because his thesis contained valuable information on the biology and movements of flounders, it was considered that this information should be prepared for publication.

It was decided to rework the raw data that were still available in the Fisheries Research Division and to incorporate other material such as statistics on tags returned during the 2 or 3 years after Dr Mundy completed his thesis. Because this thesis included results derived from some raw data which were not retained by the Division, and because of the additional material, the analysis of the available data and the conclusions that have been drawn were made independently of Dr Mundy's thesis.

I thank all those fishermen who returned tagged fish, and the staff of the Fisheries Management and Fisheries Research Divisions in Christchurch who handled the practical side of this project. Thanks also go to colleagues in the Fisheries Research Division in Wellington for their assistance, criticisms, and suggestions during the preparation of this manuscript.

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APPENDIX
DATA FOR COMPARISON OF RETURN RATES

TABLE 11: Numbers of sand flounders tagged in the Heathcote-Avon Estuary with each kind of tag and the numbers subsequently recovered

Length group (cm)	Type of tag: Tied spaghetti		Clipped spaghetti		Single Petersen disc		Double Petersen disc		All types	
	Tagged	Recovered	Tagged	Recovered	Tagged	Recovered	Tagged	Recovered	Tagged	Recovered
15-16	1	0	1	1	0	0	0	0	2	1
16-17	32	5	40	3	1	0	0	0	73	8
17-18	756	139	409	103	0	0	0	0	1 165	242
18-19	840	154	414	90	1	0	0	0	1 255	244
19-20	764	158	438	99	0	0	0	0	1 202	257
20-21	594	130	364	83	0	0	0	0	958	213
21-22	384	93	224	62	0	0	0	0	608	155
22-23	178	37	134	45	0	0	0	0	312	82
23-24	46	13	11	6	0	0	0	0	57	19
24-25	40	17	2	1	0	0	0	0	42	18
25-26	28	11	0	0	0	0	0	0	28	11
26-27	27	17	0	0	0	0	0	0	27	17
27-28	17	9	0	0	0	0	0	0	17	9
28-29	7	4	0	0	0	0	0	0	7	4
29-30	10	5	0	0	0	0	0	0	10	5
30-35	3	2	0	0	0	0	0	0	3	2
35-40	0	0	0	0	0	0	0	0	0	0
40-45	1	0	0	0	0	0	0	0	1	0
Total	3 728	794	2 037	493	2	0	0	0	5 767	1 287

TABLE 12: Numbers of sand flounders tagged in Akaroa Harbour with each kind of tag and the numbers subsequently recovered

Length group (cm)	Type of tag: Tied spaghetti		Clipped spaghetti		Single Petersen disc		Double Petersen disc		All types	
	Tagged	Recovered	Tagged	Recovered	Tagged	Recovered	Tagged	Recovered	Tagged	Recovered
15-16	8	1	1	0	1	1	3	0	13	2
16-17	46	3	23	6	7	1	9	0	85	10
17-18	429	48	139	23	23	1	26	7	617	79
18-19	400	45	157	26	45	10	45	7	647	88
19-20	400	58	154	37	49	5	61	13	664	113
20-21	339	51	178	38	65	9	63	16	645	114
21-22	337	60	150	30	80	13	73	17	640	120
22-23	302	60	155	41	90	16	73	15	620	132
23-24	223	44	90	27	73	19	97	18	483	108
24-25	158	31	78	21	102	22	80	13	418	87
25-26	118	21	37	13	74	11	79	17	308	62
26-27	74	9	34	10	24	3	31	7	163	29
27-28	54	16	31	9	12	3	9	2	106	30
28-29	46	11	22	9	6	2	6	2	80	24
29-30	45	11	9	3	4	0	3	1	61	15
30-35	197	44	30	8	19	4	5	1	251	57
35-40	72	17	7	2	4	1	2	0	85	20
40-45	6	1	2	2	0	0	0	0	8	3
Total	3 254	531	1 297	305	678	121	665	136	5 894	1 093

TABLE 13: Numbers of sand flounders tagged in Lyttelton Harbour with each kind of tag and the numbers subsequently recovered

Length group (cm)	Type of tag: Tied spaghetti		Clipped spaghetti		Single Petersen disc		Double Petersen disc		All types	
	Tagged	Recovered	Tagged	Recovered	Tagged	Recovered	Tagged	Recovered	Tagged	Recovered
15-16	2	0	0	0	0	0	0	0	2	0
16-17	19	0	20	5	1	0	0	0	40	5
17-18	316	35	112	16	1	0	4	0	433	51
18-19	288	44	96	11	13	1	10	2	407	58
19-20	234	33	93	21	18	1	10	1	355	56
20-21	208	40	80	10	16	1	13	2	317	53
21-22	190	41	104	21	15	2	13	4	322	68
22-23	162	36	74	24	15	5	25	9	276	74
23-24	116	35	83	21	16	4	22	7	237	67
24-25	116	29	64	20	17	5	12	3	209	57
25-26	116	33	62	10	9	2	17	6	204	51
26-27	87	24	58	20	0	0	0	0	145	44
27-28	89	29	44	16	0	0	1	0	134	45
28-29	62	31	28	11	1	0	0	0	91	42
29-30	66	26	22	5	0	0	0	0	88	31
30-35	82	42	42	22	0	0	0	0	124	64
35-40	2	1	2	1	0	0	0	0	4	2
40-45	1	1	1	0	0	0	0	0	2	1
Total	2 156	480	985	234	122	21	127	34	3 390	769

TABLE 14: Numbers of sand flounders tagged in each area with each type of tag and the numbers subsequently recovered, with values of χ^2 obtained in comparing rates of return between pairs of areas

Fish length at tagging (cm)		Estuary Tagged	Estuary Recovered Observed	Estuary Recovered Expected	Akaroa Tagged	Akaroa Recovered Observed	Akaroa Recovered Expected	Total Tagged	Total Recovered	χ^2
Tied spaghetti										
15-18		789	144	121.58	483	52	74.42	1 272	196	10.9***
18-19		840	154	134.81	400	45	64.19	1 240	199	8.5**
19-20		764	158	141.77	400	58	74.23	1 164	216	5.4*
20-21		594	130	115.23	339	51	65.77	933	181	5.2*
21-22		384	93	81.49	337	60	71.51	721	153	3.5 n.s.
22-23		178	37	35.97	302	60	61.03	480	97	0.0 n.s.
23-24		46	13	9.75	223	44	47.25	269	57	1.3 n.s.
24-25		40	17	9.70	158	31	38.30	198	48	6.9**
25-26		28	11	6.14	118	21	25.86	146	32	4.8*
26-27		27	17	6.95	74	9	19.05	101	26	19.8***
27-28		17	9	5.99	54	16	19.01	71	25	2.0 n.s.
>28		21	11	5.16	366	84	89.84	387	95	7.0**
										$\Sigma\chi^2$ 75.3*** (12 d.f.)
	Total	3 728	794	707.48	3 254	531	617.52	6 982	1 325	Pooled χ^2 22.7*** (1 d.f.) Heterogeneity χ^2 52.6*** (11 d.f.)
Clipped spaghetti										
15-18		450	107	99.84	163	29	36.16	613	136	1.9 n.s.
18-19		414	90	84.11	157	26	31.89	571	116	1.5 n.s.
19-20		438	99	100.62	154	37	35.38	592	136	0.1 n.s.
20-21		364	83	81.26	178	38	39.74	542	121	0.1 n.s.
21-22		224	62	55.10	150	30	36.90	374	92	2.2 n.s.
22-23		134	45	39.88	155	41	46.12	289	86	1.2 n.s.
>23		13	7	4.09	340	104	106.91	353	111	2.1 n.s.
										$\Sigma\chi^2$ 9.1 n.s. (7 d.f.)
	Total	2 037	493	487.56	1 297	305	310.44	3 334	798	Pooled χ^2 0.2 n.s. (1 d.f.) Heterogeneity χ^2 9.0 n.s. (6 d.f.)

		Estuary			Lyttelton			Total		
Tied spaghetti										
15-18		789	144	125.43	337	35	53.57	1 126	179	9.2**
18-19		840	154	147.45	288	44	50.55	1 128	198	1.1 n.s.
19-20		764	158	146.22	234	33	44.78	998	191	4.0*
20-21		594	130	125.91	208	40	44.09	802	170	0.5 n.s.
21-22		384	93	89.64	190	41	44.36	574	134	0.4 n.s.
22-23		178	37	38.22	162	36	34.78	340	73	0.1 n.s.
23-24		46	13	13.63	116	35	34.37	162	48	0.0 n.s.
24-25		40	17	11.79	116	29	34.21	156	46	3.1 n.s.
25-26		28	11	8.56	116	33	35.44	144	44	0.9 n.s.
26-27		27	17	9.71	87	24	31.29	114	41	7.2**
27-28		17	9	6.09	89	29	31.91	106	38	1.7 n.s.
>28		21	11	10.05	213	101	101.95	234	112	0.1 n.s.
										$\Sigma\chi^2$ 28.3** (12 d.f.)
	Total	3 728	794	807.18	2 156	480	466.82	5 884	1 274	Pooled χ^2 0.6 n.s. (1 d.f.) Heterogeneity χ^2 27.7** (11 d.f.)
Clipped spaghetti										
15-18		450	107	98.97	132	21	29.03	582	128	2.9 n.s.
18-19		414	90	81.99	96	11	19.01	510	101	4.2*
19-20		438	99	98.98	93	21	21.02	531	120	0.0 n.s.
20-21		364	83	76.24	80	10	16.76	444	93	3.3 n.s.
21-22		224	62	56.68	104	21	26.32	328	83	1.6 n.s.
22-23		134	45	44.45	74	24	24.55	208	69	0.0 n.s.
>23		13	7	4.13	406	126	128.87	419	133	2.1 n.s.
										$\Sigma\chi^2$ 14.1* (7 d.f.)
	Total	2 037	493	490.04	985	234	236.96	3 022	727	Pooled χ^2 0.1 n.s. (1 d.f.) Heterogeneity χ^2 14.0* (6 d.f.)

* Significant at the 5% level.
** Significant at the 1% level.
*** Significant at the 0.1% level.
n.s.: Not significant.

TABLE 14: Numbers of sand flounders tagged in each area with each type of tag and the numbers subsequently recovered, with values of χ^2 obtained in comparing rates of return between pairs of areas (continued)

Fish length at tagging (cm)	Akaroa Tagged	Akaroa Recovered Observed	Akaroa Recovered Expected	Lyttelton Tagged	Lyttelton Recovered Observed	Lyttelton Recovered Expected	Total Tagged	Total Recovered	χ^2
Tied spaghetti									
15-18	483	52	51.25	337	35	35.75	820	87	0.0 n.s.
18-19	400	45	51.74	288	44	37.26	688	89	2.1 n.s.
19-20	400	58	57.41	234	33	33.59	634	91	0.0 n.s.
20-21	339	51	56.40	208	40	34.60	547	91	1.4 n.s.
21-22	337	60	64.59	190	41	36.41	527	101	0.9 n.s.
22-23	302	60	62.48	162	36	33.52	464	96	0.3 n.s.
23-24	223	44	51.97	116	35	27.03	339	79	3.6 n.s.
24-25	158	31	34.60	116	29	25.40	274	60	0.9 n.s.
25-26	118	21	27.23	116	33	26.77	234	54	2.9 n.s.
26-27	74	9	15.17	87	24	17.83	161	33	4.6*
27-28	54	16	16.99	89	29	28.01	143	45	0.1 n.s.
28-29	46	11	17.89	62	31	24.11	108	42	4.6*
29-30	45	11	15.00	66	26	22.00	111	37	1.8 n.s.
>30	275	62	80.97	85	44	25.03	360	106	18.8***
									$\Sigma\chi^2$ 42.0*** (14 d.f.)
Total	3 254	531	608.10	2 156	480	402.90	5 410	1 011	Pooled χ^2 24.5*** (1 d.f.)
									Heterogeneity χ^2 17.5 n.s. (13 d.f.)
Clipped spaghetti									
15-18	163	29	27.63	132	21	22.37	295	50	0.2 n.s.
18-19	157	26	22.96	96	11	14.04	253	37	1.1 n.s.
19-20	154	37	36.16	93	21	21.84	247	58	0.1 n.s.
20-21	178	38	33.12	80	10	14.88	258	48	2.3 n.s.
21-22	150	30	30.12	104	21	20.88	254	51	0.0 n.s.
22-23	155	41	44.00	74	24	21.00	229	65	0.6 n.s.
23-24	90	27	24.97	83	21	23.03	173	48	0.3 n.s.
24-25	78	21	22.52	64	20	18.48	142	41	0.2 n.s.
25-26	37	13	8.60	62	10	14.40	99	23	3.6 n.s.
26-27	34	10	11.09	58	20	18.91	92	30	0.2 n.s.
27-28	31	9	10.33	44	16	14.67	75	25	0.3 n.s.
28-30	31	12	10.72	50	16	17.28	81	28	0.2 n.s.
>30	39	12	16.25	45	23	18.75	84	35	2.1 n.s.
									$\Sigma\chi^2$ 11.2 n.s. (13 d.f.)
Total	1 297	305	306.35	985	234	232.65	2 282	539	Pooled χ^2 0.0 n.s. (1 d.f.)
									Heterogeneity χ^2 11.2 n.s. (12 d.f.)
Single Petersen disc									
15-22	270	40	36.38	64	5	8.62	334	45	1.9 n.s.
22-24	163	35	36.97	31	9	7.03	194	44	0.7 n.s.
>24	245	46	47.74	27	7	5.26	272	53	0.6 n.s.
									$\Sigma\chi^2$ 3.2 n.s. (3 d.f.)
Total	678	121	120.35	122	21	21.65	800	142	Pooled χ^2 0.0 n.s. (1 d.f.)
									Heterogeneity χ^2 3.2 n.s. (2 d.f.)
Double Petersen disc									
15-22	280	60	58.55	50	9	10.45	330	69	0.2 n.s.
22-23	73	15	17.88	25	9	6.12	98	24	1.8 n.s.
23-24	97	18	20.38	22	7	4.62	119	25	1.5 n.s.
>24	215	43	45.63	30	9	6.37	245	52	1.2 n.s.
									$\Sigma\chi^2$ 4.7 n.s. (4 d.f.)
Total	665	136	142.74	127	34	27.26	792	170	Pooled χ^2 2.0 n.s. (1 d.f.)
									Heterogeneity χ^2 2.7 n.s. (3 d.f.)

* Significant at the 5% level.
** Significant at the 1% level.
*** Significant at the 0.1% level.
n.s.: Not significant.

TABLE 14: Numbers of sand flounders tagged in each area with each type of tag and the numbers subsequently receovered, with values of χ^2 obtained in comparing rates of return between pairs of areas (continued)

Fish length at tagging (cm)	Akaroa Tagged	Akaroa Recovered Observed	Akaroa Recovered Expected	Lyttelton Tagged	Lyttelton Recovered Observed	Lyttelton Recovered Expected	Total Tagged	Total Recovered	χ^2
Overall returns									
15-17	98	12	11.90	42	5	5.10	140	17	0.0 n.s.
17-18	617	79	76.39	433	51	53.61	1 050	130	0.2 n.s.
18-19	647	88	89.62	407	58	56.38	1 054	146	0.1 n.s.
19-20	664	113	110.12	355	56	58.88	1 019	169	0.2 n.s.
20-21	645	114	111.97	317	53	55.03	962	167	0.1 n.s.
21-22	640	120	125.07	322	68	62.93	962	188	0.6 n.s.
22-23	620	132	142.54	276	74	63.46	896	206	2.5 n.s.
23-24	483	108	117.40	237	67	57.60	720	175	2.3 n.s.
24-25	418	87	96.00	209	57	48.00	627	144	2.5 n.s.
25-26	308	62	67.98	204	51	45.02	512	113	1.3 n.s.
26-27	163	29	38.63	145	44	34.37	308	73	5.1*
27-28	106	30	33.13	134	45	41.87	240	75	0.5 n.s.
28-29	80	24	30.88	91	42	35.12	171	66	2.9 n.s.
29-30	61	15	18.83	88	31	27.17	149	46	1.3 n.s.
>30	344	80	106.68	130	67	40.32	474	147	24.3***
									$\Sigma\chi^2$ 43.9*** (15 d.f.)
Total	5 894	1093	1 182.10	3 390	769	679.90	9 284	1 862	Pooled χ^2 18.4*** (1 d.f.)
									Heterogeneity χ^2 25.5* (14 d.f.)

Overall returns	Estuary Tagged	Estuary Recovered Observed	Estuary Recovered Expected	Lyttelton Tagged	Lyttelton Recovered Observed	Lyttelton Recovered Expected	Total Tagged	Total Recovered	χ^2
15-17	75	9	8.97	42	5	5.03	117	14	0.0 n.s.
17-18	1 165	242	213.61	433	51	79.39	1 598	293	13.9***
18-19	1 255	244	228.04	407	58	73.96	1 662	302	4.6*
19-20	1 202	257	241.64	355	56	71.36	1 557	313	4.3*
20-21	958	213	199.87	317	53	66.13	1 275	266	3.5 n.s.
21-22	608	155	145.79	322	68	77.21	930	223	1.7 n.s.
22-23	312*	82	82.78	276	74	73.22	588	156	0.0 n.s.
23-24	57	19	16.67	237	67	69.33	294	86	0.4 n.s.
24-25	42	18	12.55	209	57	62.45	251	75	2.8 n.s.
25-26	28	11	7.48	204	51	54.52	232	62	1.9 n.s.
26-27	27	17	9.58	145	44	51.42	172	61	6.8**
27-28	17	9	6.08	134	45	47.92	151	54	1.6 n.s.
>28	21	11	9.61	309	140	141.39	330	151	0.2 n.s.
									$\Sigma\chi^2$ 41.7*** (13 d.f.)
Total	5 767	1 287	1 294.85	3 390	769	761.15	9 157	2 056	Pooled χ^2 0.1 n.s. (1 d.f.)
									Heterogeneity χ^2 41.6*** (12 d.f.)

Overall returns	Estuary Tagged	Estuary Recovered Observed	Estuary Recovered Expected	Akaroa Tagged	Akaroa Recovered Observed	Akaroa Recovered Expected	Total Tagged	Total Recovered	χ^2
15-17	75	9	9.10	98	12	11.90	173	21	0.0 n.s.
17-18	1 165	242	209.86	617	79	111.14	1 782	321	14.2***
18-19	1 255	244	219.06	647	88	112.94	1 902	332	8.3**
19-20	1 202	257	238.34	664	113	131.66	1 866	370	4.1*
20-21	958	213	195.42	645	114	131.58	1 603	327	3.9*
21-22	608	155	133.97	640	120	141.03	1 248	275	6.4*
22-23	312	82	71.64	620	132	142.36	932	214	2.3 n.s.
23-24	57	19	13.41	483	108	113.59	540	127	2.6 n.s.
24-25	42	18	9.59	418	87	95.41	460	105	8.1**
25-26	28	11	6.08	308	62	66.92	336	73	4.3*
26-27	27	17	6.54	163	29	39.46	190	46	19.5***
27-28	17	9	5.39	106	30	33.61	123	39	2.8 n.s.
>28	21	11	5.40	485	119	124.60	506	130	6.1*
									$\Sigma\chi^2$ 82.6*** (13 d.f.)
Total	5 767	1 287	1 177.04	5 894	1 093	1 202.96	11 661	2 380	Pooled χ^2 20.3*** (1 d.f.)
									Heterogeneity χ^2 62.3*** (12 d.f.)

* Significant at the 5% level.
** Significant at the 1% level.
*** Significant at the 0.1% level.
n.s.: Not significant.

TABLE 15: Numbers of sand flounders tagged in each area with each type of tag and the numbers recovered, with values of χ^2 obtained in comparing rates of return, within areas, with different types of tag

Fish length at tagging (cm)	Tied spaghetti			Clipped spaghetti			Total		
	Tagged	Recovered Observed	Expected	Tagged	Recovered Observed	Expected	Tagged	Recovered	χ^2
Estuary									
15-18	789	144	159.84	450	107	91.16	1 239	251	4.3*
18-19	840	154	163.44	414	90	80.56	1 254	244	1.7 n.s.
19-20	764	158	163.35	438	99	93.65	1 202	257	0.5 n.s.
20-21	594	130	132.07	364	83	80.93	958	213	0.1 n.s.
21-22	384	93	97.89	224	62	57.11	608	155	0.7 n.s.
22-23	178	37	46.78	134	45	35.22	312	82	4.8*
>23	179	78	79.24	13	7	5.76	192	85	0.3 n.s.
									$\Sigma\chi^2$ 12.4 n.s. (7 d.f.)
Total	3 728	794	832.25	2 037	493	454.75	5 765	1 287	Pooled χ^2 5.0* (1 d.f.)
									Heterogeneity χ^2 7.4 n.s. (6 d.f.)
Lyttelton									
15-18	337	35	40.24	132	21	15.76	469	56	2.4 n.s.
18-19	288	44	41.25	96	11	13.75	384	55	0.7 n.s.
19-20	234	33	38.64	93	21	15.36	327	54	2.9 n.s.
20-21	208	40	36.11	80	10	13.89	288	50	1.5 n.s.
21-22	190	41	40.07	104	21	21.93	294	62	0.1 n.s.
22-23	162	36	41.19	74	24	18.81	236	60	2.1 n.s.
23-24	116	35	32.64	83	21	23.36	199	56	0.4 n.s.
24-25	116	29	31.58	64	20	17.42	180	49	0.6 n.s.
25-26	116	33	28.02	62	10	14.98	178	43	2.5 n.s
26-27	87	24	26.40	58	20	17.60	145	44	0.5 n.s.
27-28	89	29	30.11	44	16	14.89	133	45	0.1 n.s.
28-29	62	31	28.93	28	11	13.07	90	42	0.5 n.s.
29-30	66	26	23.25	22	5	7.75	88	31	1.3 n.s.
>30	85	44	43.81	45	23	23.19	130	67	0.0 n.s.
									$\Sigma\chi^2$ 15.6 n.s. (14 d.f.)
Total	2 156	480	490.09	985	234	223.91	3 141	714	Pooled χ^2 0.7 n.s. (1 d.f.)
									Heterogeneity χ^2 14.9 n.s. (13 d.f.)
Akaroa									
15-18	483	52	60.56	163	29	20.44	646	81	4.8*
18-19	400	45	50.99	157	26	20.01	557	71	2.5 n.s.
19-20	400	58	68.59	154	37	26.41	554	95	5.9*
20-21	339	51	58.36	178	38	30.64	517	89	2.7 n.s.
21-22	337	60	62.28	150	30	27.72	487	90	0.3 n.s.
22-23	302	60	66.74	155	41	34.26	457	101	2.0 n.s.
23-24	223	44	50.58	90	27	20.42	313	71	3.0 n.s.
24-25	158	31	34.81	78	21	17.19	236	52	1.3 n.s.
25-26	118	21	25.88	37	13	8.12	155	34	3.9*
26-27	74	9	13.02	34	10	5.98	108	19	3.9*
27-28	54	16	15.88	31	9	9.12	85	25	0.0 n.s.
28-30	91	22	25.36	31	12	8.64	122	34	1.8 n.s.
>30	275	62	64.81	39	12	9.19	314	74	1.0 n.s.
									$\Sigma\chi^2$ 33.1** (13 d.f.)
Total	3 254	531	597.75	1 297	305	238.25	4 551	836	Pooled χ^2 26.2*** (1 d.f.)
									Heterogeneity χ^2 6.9 n.s. (12 d.f.)
Akaroa	Tied spaghetti			Single P.d.					
15-19	883	97	101.28	76	13	8.72	959	110	2.3 n.s.
19-20	400	58	56.12	49	5	6.88	449	63	0.6 n.s.
20-21	339	51	50.35	65	9	9.65	404	60	0.1 n.s.
21-22	337	60	59.00	80	13	14.00	417	73	0.1 n.s.
22-23	302	60	58.55	90	16	17.45	392	76	0.2 n.s.
23-24	223	44	47.46	73	19	15.54	296	63	1.0 n.s.
24-25	158	31	32.21	102	22	20.79	260	53	0.1 n.s.
25-26	118	21	19.67	74	11	12.33	192	32	0.2 n.s.
26-30	219	47	45.45	46	8	9.55	265	55	0.3 n.s.
>30	275	62	61.83	23	5	5.17	298	67	0.0 n.s.
									$\Sigma\chi^2$ 4.9 n.s. (10 d.f.)
Total	3 254	531	539.57	678	121	112.43	3 932	652	Pooled χ^2 0.8 n.s. (1 d.f.)
									Heterogeneity χ^2 4.1 n.s. (9 d.f.)

*Significant at the 5% level.
**Significant at the 1% level.
***Significant at the 0.1% level.
n.s.: Not significant.

TABLE 15: Numbers of sand flounders tagged in each area with each type of tag and the numbers recovered, with values of χ^2 obtained in comparing rates of return, within areas, with different types of tag (continued)

Fish length at tagging (cm)	Tied spaghetti Tagged	Recovered Observed	Recovered Expected	Single P.d. Tagged	Recovered Observed	Recovered Expected	Total Tagged	Total Recovered	χ^2
Lyttelton									
15-22	1 257	193	188.41	64	5	9.59	1 321	198	2.3 n.s.
22-24	278	71	71.97	31	9	8.03	309	80	0.1 n.s.
>24	621	216	213.71	27	7	9.29	648	223	0.6 n.s.
									$\Sigma\chi^2$ 3.0 n.s. (3 d.f.)
Total	2 156	480	474.17	122	21	26.83	2 278	501	Pooled χ^2 1.3 n.s. (1 d.f.)
									Heterogeneity χ^2 1.7 n.s. (2 d.f.)
Lyttelton	Tied spaghetti			Double P.d.					
15-22	1 257	193	194.27	50	9	7.73	1 307	202	0.2 n.s.
22-23	162	36	38.98	25	9	6.02	187	45	1.7 n.s.
23-24	116	35	35.30	22	7	6.70	138	42	0.0 n.s.
>24	621	216	214.63	30	9	10.37	651	225	0.2 n.s.
									$\Sigma\chi^2$ 2.1 n.s. (4 d.f.)
Total	2 156	480	485.41	127	34	28.59	2 283	514	Pooled χ^2 1.1 n.s. (1 d.f.)
									Heterogeneity χ^2 1.0 n.s. (3.d.f.)
Akaroa									
15-18	483	52	54.70	38	7	4.30	521	59	1.8 n.s.
18-19	400	45	46.74	45	7	5.26	445	52	0.6 n.s.
19-20	400	58	61.61	61	13	9.39	461	71	1.6 n.s.
20-21	339	51	56.50	63	16	10.50	402	67	3.4 n.s.
21-22	337	60	63.29	73	17	13.71	410	77	1.0 n.s.
22-23	302	60	60.40	73	15	14.60	375	75	0.0 n.s.
23-24	223	44	43.21	97	18	18.79	320	62	0.0 n.s.
24-25	158	31	29.21	80	13	14.79	238	44	0.3 n.s.
25-26	118	21	22.76	79	17	15.24	197	38	0.3 n.s.
26-27	74	9	11.28	31	7	4.72	105	16	1.6 n.s.
>27	420	100	100.04	25	6	5.96	445	106	0.0 n.s.
									$\Sigma\chi^2$ 10.6 n.s. (11 d.f.)
Total	3 254	531	553.82	665	136	113.18	3 919	667	Pooled χ^2 5.5* (1 d.f.)
									Heterogeneity χ^2 5.1 n.s. (10 d.f.)
Lyttelton	Clipped spaghetti			Single P.d.					
15-22	505	84	78.99	64	5	10.01	569	89	2.8 n.s.
22-24	157	45	45.10	31	9	8.90	188	54	0.0 n.s.
>24	323	105	103.36	27	7	8.64	350	112	0.3 n.s.
									$\Sigma\chi^2$ 3.1 n.s. (3 d.f.)
Total	985	234	226.90	122	21	28.10	1 107	255	Pooled χ^2 2.0 n.s. (1 d.f.)
									Heterogeneity χ^2 1.1 n.s. (2 d.f.)
Akaroa									
15-19	320	55	54.95	76	13	13.05	396	68	0.0 n.s.
19-20	154	37	31.86	49	5	10.14	203	42	3.4 n.s.
20-21	178	38	34.43	65	9	12.57	243	47	1.4 n.s.
21-22	150	30	28.04	80	13	14.96	230	43	0.4 n.s.
22-23	155	41	36.06	90	16	20.94	245	57	1.8 n.s.
23-24	90	27	25.40	73	19	20.60	163	46	0.2 n.s.
24-25	78	21	18.63	102	22	24.37	180	43	0.5 n.s.
25-26	37	13	8.00	74	11	16.00	111	24	4.7*
26-30	96	31	26.37	46	8	12.63	142	39	2.5 n.s.
>30	39	12	10.69	23	5	6.31	62	17	0.4 n.s.
									$\Sigma\chi^2$ 15.3 n.s. (10 d.f.)
Total	1 297	305	279.76	678	121	146.24	1 975	426	Pooled χ^2 6.6* (1 d.f.)
									Heterogeneity χ^2 8.7 n.s. (9 d.f.)

*Significant at the 5% level.
**Significant at the 1% level.
***Significant at the 0.1% level.
n.s.: Not significant.

TABLE 15: Numbers of sand flounders tagged in each area with each type of tag and the numbers recovered, with values of χ^2 obtained in comparing rates of return, within areas, with different types of tag (continued)

Fish length at tagging (cm)		Clipped spaghetti Tagged	Recovered Observed	Expected	Double P.d. Tagged	Recovered Observed	Expected	Total Tagged	Recovered	χ^2
Akaroa										
15-18		163	29	29.19	38	7	6.81	201	36	0.0 n.s.
18-19		157	26	25.65	45	7	7.35	202	33	0.0 n.s.
19-20		154	37	35.81	61	13	14.19	215	50	0.1 n.s.
20-21		178	38	39.88	63	16	14.12	241	54	0.3 n.s.
21-22		150	30	31.61	73	17	15.39	223	47	0.3 n.s.
22-23		155	41	38.07	73	15	17.93	228	56	0.7 n.s.
23-24		90	27	21.66	97	18	23.34	187	45	2.5 n.s.
24-25		78	21	16.78	80	13	17.22	158	34	2.1 n.s.
25-26		37	13	9.57	79	17	20.43	116	30	1.8 n.s.
26-27		34	10	8.89	31	7	8.11	65	17	0.3 n.s.
> 27		101	33	31.26	25	6	7.74	126	39	0.5 n.s.
										$\Sigma\chi^2$ 8.6 n.s. (11 d.f.)
	Total	1 297	305	291.53	665	136	149.47	1 962	441	Pooled χ^2 1.8 n.s. (1 d.f.)
										Heterogeneity χ^2 6.8 n.s. (10 d.f.)
Lyttelton										
15-22		505	84	84.62	50	9	8.38	555	93	0.1 n.s.
22-23		74	24	24.67	25	9	8.33	99	33	0.1 n.s.
23-24		83	21	22.13	22	7	5.87	105	28	0.3 n.s.
>24		323	105	104.31	30	9	9.69	353	114	0.1 n.s.
										$\Sigma\chi^2$ 0.6 n.s. (4 d.f.)
	Total	985	234	237.39	127	34	30.61	1 112	268	Pooled χ^2 0.4 n.s. (1 d.f.)
										Heterogeneity χ^2 0.2 n.s. (3 d.f.)
Lyttelton		Single P.d.			Double P.d.					
15-22		64	5	7.86	50	9	6.14	114	14	2.4 n.s.
22-24		31	9	9.94	47	16	15.06	78	25	0.1 n.s.
> 24		27	7	7.58	30	9	8.42	57	16	0.1 n.s.
										$\Sigma\chi^2$ 2.6 n.s. (3 d.f.)
	Total	122	21	26.95	127	34	28.05	249	55	Pooled χ^2 2.6 n.s. (1 d.f.)
										Heterogeneity χ^2 0.0 n.s. (2 d.f.)
Akaroa										
15-19		76	13	12.91	83	14	14.09	159	27	0.0 n.s.
19-20		49	5	8.02	61	13	9.98	110	18	2.1 n.s.
20-21		65	9	12.70	63	16	12.30	128	25	2.2 n.s.
21-22		80	13	15.69	73	17	14.31	153	30	1.0 n.s.
22-23		90	16	17.12	73	15	13.88	163	31	0.2 n.s.
23-24		73	19	15.89	97	18	21.11	170	37	1.1 n.s.
24-25		102	22	19.62	80	13	15.38	182	35	0.7 n.s.
25-26		74	11	13.54	79	17	14.46	153	28	0.9 n.s.
>26		69	13	14.35	56	13	11.65	125	26	0.3 n.s.
										$\Sigma\chi^2$ 8.5 n.s. (9 d.f.)
	Total	678	121	129.74	665	136	127.26	1 343	257	Pooled χ^2 1.2 n.s. (1 d.f.)
										Heterogeneity χ^2 7.3 n.s. (8 d.f.)

*Significant at the 5% level.
**Significant at the 1% level.
***Significant at the 0.1% level.
n.s.: Not significant.

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